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NUCLEAR INSTRUMENTS

A JOURNAL ON ACCELERATORS, INSTRUMENTATION AND TECHNIQUES IN NUCLEAR PHYSICS

EDITOR K. SIEGBAHN - UPPSALA

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NUCLEAR INSTRUMENTS

A journal on accelerators, instrumentation and techniques in nuclear physics

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DEMULTIPLICATEURS ELECTRONIQUES D'IMPULSIONS

Ière Partie

RATIONALISATION DES CIRCUITS DE NUMERATION

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Received 15 November

The first part of this publication deals with new electronic circuits for impulsion numeration. These circuits, more pratical than the binary decades, allow superior performances. An original device helps to reduce the decade resolution time, in regard to haphasardly distributed impulsions, to that of wave-form shaping circuit. Thus we almost eliminate the statistical loss in counting.

1. Introduction

La publication rédigée sous ce titre est le condensé d'une thèse de doctorat ayant pour objectifs principaux la rationalisation de circuits démultiplicateurs conventionnels et l'étude de dispositifs capables de dénombrer des impulsions de fréquence très élevée (plusieurs dizaines de mégacycles/sec).

Dans sa forme initiale cet exposé comporterait un premier chapitre consacré à l'étude théorique de l'étage Eccles-Jordan[1]) et de la décade binaire du type R.C.A. qui en est issue, circuits dont les qualités remarquables justifient le choix que nous en avons fait comme dispositifs de référence pour la comparaison de nos résultats. La nécessité de condenser au maximum le texte original nous contraint de renoncer au développement de ce sujet.

L'analyse mathématique s'applique mal aux dispositifs électroniques travaillant hors du domaine linéaire des caractéristiques des tubes. La comparaison objective et le calcul des circuits ne permettent toutefois pas de faire totale abstraction de tels développements. On s'est efforcé de les simplifier en considérant les transitions comme une suite d'événements, facilement accessibles individuellement à l'analyse. Complétée d'investigations expérimentales précises, cette méthode satisfait en général à l'étude des démultiplicateurs à basse fréquence.

Le problème se présente sous un aspect différent dans la seconde partie de cet exposé, consacrée aux applications du tube à émission secondaire à la numération d'impulsions à haute fréquence. Les fronts d'onde sont d'une telle rapidité que l'observation directe à l'oscilloscope perd son objectivité par suite d'inévitables déformations. Différentes méthodes ont été appliquées en vue d'améliorer l'exactitude des résultats expérimentaux mais il faut convenir que la solution mathématique est ici le plus puissant moyen d'investigation. Le domaine linéaire remarquablement étendu du genre de tubes utilisés dans ces recherches, facilite d'ailleurs les choses.

Les lecteurs voudront bien nous excuser du manque de détails de cet exposé dont les exigeances de l'édition ont nécessité la réduction au quart du texte original.

2. Circuits Electroniques Multistables

2.1. Les caractéristiques optimum d'un démultiplicateur d'impulsions composé de circuit à détente (trigger) sont obtenues en opérant le couplage électronique des étages, d'ou l'intérêt d'en réduire le nombre. La décade binaire, avec ses trois couplages internes, n'est pas favorisée à cet égard. Elle ne l'est pas plus quant au nombre

[1]) W. H. Eccles and F. W. Jordan, Radio Review 1919.

de rétrocouplages qui contribuent à réduire la stabilité et le pouvoir de résolution.

Plusieurs réalisations faisant appel au couplage de tubes en chaîne fermée ont fait l'objet de brevets et comme tels ne figurent pas dans la bibliographie scientifique. Certaines d'entre elles ne sont parvenues que récemment à notre connaissance à la suite de recherches entreprises par une Maison spécialisée. Parmi les plus connues figurent l'anneau de Regener[2]) et l'échelle généralisée de Mumma[3]) auxquelles s'ajoutent une dizaine de solutions plus ou moins intéressantes, sans qu'aucune ne satisfasse aux conditions de simplicité, stabilité et rapidité requises.

Nous avons déjà mentionné une solution faisant appel à une chaîne fermée comportant un nombre impair de tubes électroniques alternativement bloqués et conducteurs, à l'exception de deux d'entre eux dans le même état bien qu'adjacents[4]). Le rang de ce couplage de tubes particuliers distingue les différentes configurations. L'état d'un tube donné ne dépendant que de celui des deux tubes voisins, une chaîne de ce type peut être réalisée par un couplage conforme au schéma de la fig. 1.

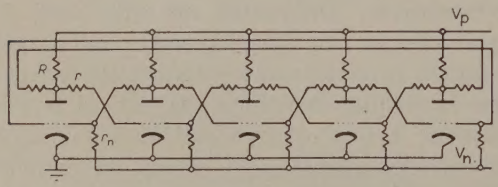

Fig. 1

Les deux tubes adjacents dans le même état peuvent être bloqués ou conducteurs, donnant lieu aux circuits que l'on appellera "à couple de tubes adjacents bloqués", respectivement "conducteurs".

Soient:

V_b = tension anodique des tubes bloqués
V_c = tension anodique des tubes conducteurs
$V_k = 0$ = tension cathodique prise comme référence
V_n = tension négative de polarisation
V_{gp} = tension nominale de polarisation de grille du tube conducteur, déterminée en faisant abstraction du courant de grille
V_{gn} = tension nominale de polarisation de grille du tube bloqué
V_{gc} = tension de blocage (cut-off)
R = résistance anodique
r = résistance de couplage
r_n = résistance de polarisation négative des grilles

On introduira encore la notion de surpolarisation positive ΔV_{gp} respectivement négative ΔV_{gn}, grandeurs définies par les relations:

$$\Delta V_{gp} = V_{gp} - V_k \qquad \Delta V_{gn} = V_{gc} - V_{gn} \ .$$

Le coefficient de stabilité statique S d'une chaîne du type susmentionné est convenablement déterminé par la tolérance de la résistance r_n, tirée de fonctions $f(\Delta V_{gn},...)$ et $F(\Delta V_{gp},...)$:

$$S \cong \begin{cases} + 100 \cdot f(\Delta V_{gn},...) \ \% \\ - 100 \cdot F(\Delta V_{gp},...) \ \% \ . \end{cases}$$

La symétrie de cette relation implique une valeur bien déterminée du rapport r/r_n. On a alors:

$$S \cong \pm 100 \cdot f(\Delta V_{gn},...) \ \% = \pm 100 \cdot F(\Delta V_{gp},...) \ \% \ .$$

Nous n'insisterons pas sur les chaînes à couple de tubes adjacents bloqués qui donnent un coefficient de stabilité très faible.

2.2. CHAÎNES TERNAIRES À COUPLE DE TUBES ADJACENTS CONDUCTEURS

Les conditions de polarisation à satisfaire se caractérisent par le fait qu'un tube compris entre deux tubes conducteurs doit être bloqué tandis qu'il sera conducteur si l'un au moins des tubes adjacents est bloqué.

[2]) Victor H. Regener, Decade counting circuits, Rev. Sci. Inst. **17** (1948) 185–189.

[3]) R. E. Mumma, Electronic accumulator, Brev. U.S.A. 2'405'664.

[4]) R. Favre, Circuits électroniques multistables et décades Helv. Phys. Acta **28** (1954) 235–240.

$$\Delta V_{gp} = \frac{(V_b + V_c)\, r_n + V_n \cdot r}{2r_n + r}$$

$$\Delta V_{gn} = V_{gc} - \frac{2V_c \cdot r_n + V_n \cdot r}{2r_n + r}$$

avec la condition:

$$\frac{V_n \cdot r}{(V_b + V_c) r_n} + 1 = \frac{(V_{gc} - V_n) r}{(V_c - V_{gc})\, 2r_n} - 1$$

d'où:

$$\frac{r_n}{r} = \frac{V_{gc} - V_n}{(V_c - V_{gc})} - \frac{V_n}{2(V_b + V_c)} , \qquad (1)$$

$$S \cong \pm 100 \cdot \left(\frac{V_n \cdot r}{(V_b + V_c)\, r_n} + 1 \right) \% . \qquad (2)$$

Les chaines quinaires de ce type sont caractérisées par deux états de polarisation positive.

2.3. APPLICATION NUMÉRIQUE

Soient:

$V_b = 200$ V $\quad V_c = 50$ V $\quad V_n = -60$ V $\quad V_{gc} = -10$ V

(a) Couple de tubes adjacents bloqués. On trouve:

$$r/r_n = 6 \qquad S = \pm 10\% .$$

(b) Couple de tubes adjacents conducteurs. On trouve:

$$r/r_n = 3.15 \qquad S = \pm 28\% .$$

Dans les mêmes conditions l'étage Eccles-Jordan accuse un coefficient de stabilité $S = \pm 48\%$. Une stabilité homogène des différentes fonctions est cependant préférable, pour la sécurité de fonctionnement, qu'une valeur inutilement élevée à certains égards mais insuffisante à d'autres.

Les circuits à couple de tubes adjacents conducteurs sont toutefois incontestablement supérieurs à leur concurrent. Ils permettent notamment l'emploi de résistances standard à $\pm 10\%$ On montrera de plus qu'ils se prêtent mieux au couplage par tubes électroniques et à la réalisation de décades.

2.4. COUPLAGE DYNAMIQUES DES CHAÎNES

La permutation des configurations stables nécessite un couplage dynamique des éléments du circuit. Une capacité placée entre l'anode de chaque tube et la grille du suivant permet en principe d'obtenir une permutation cyclique mais l'anode d'un tube se trouve ainsi couplée à sa grille par l'élément retardateur que constitue la chaîne, d'où la possibilité d'oscillations particulièrement manifeste sur les circuits constitués de triodes. Un artifice d'amortissement propre à affaiblir suffisamment la fréquence de résonance transmise par la chaîne est nécessaire à son fonctionnement correct.

Laissons de côté les chaînes à couple de tubes adjacents bloqués, d'un intérêt secondaire, pour ne rappeler qu'un artifice appliqué avec succès aux chaînes à couple de tubes adjacents conducteurs. Il s'agit d'une simple coupure dans le couplage dynamique de la chaîne. L'action du condensateur manquant est remplacée par une réaction différée[4]) où, dans certaines décades, est assumée par l'intermédiaire d'un étage binaire[5]). Ce dernier cas étant exposé en détail dans le chapitre relatif aux décades, nous nous limiterons à la description du premier. Pour le comprendre il faut préciser que seules les impulsions d'attaque positives sur grilles sont applicables aux chaînes à couple de tubes adjacents conducteurs.

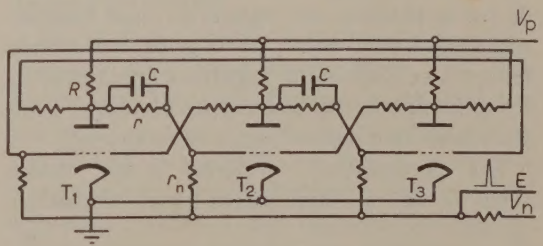

Fig. 2

Les permutations d'une chaîne selon la fig. 2, à laquelle manque l'un des condensateurs de couplage, se comprennent de la manière suivante:

Soient: T_1 bloqué, T_2 et T_3 conducteurs.

Première impulsion

T_1 est débloqué et, par couplage dynamique, bloque T_2.

Deuxième impulsion

T_2 est débloqué et, par couplage dynamique, bloque T_3.

[5]) R. Favre, Circuit multistable composé à cycle quinaire naturel, Helv. Phys. Acta **28** (1955) 235–240.

Troisième impulsion

T_3 est débloqué sans qu'il en résulte de blocage immédiat.

A la fin de l'impulsion d'attaque, les conditions de couplage continu ne sont plus compatibles avec l'état conducteur des trois tubes. C'est alors le potentiel de la grille de T_1, chargée de sa seule capacité propre, qui s'abaisse le premier en fermant le cycle par une transition "différée".

La sécurité de la troisième permutation est améliorée par un petit condensateur placé entre la grille de T_3 et l'anode de T_1. Une impulsion positive, consécutive au blocage de ce dernier, étant alors transmise sur la grille des deux autres tubes les maintient conducteurs.

La suppression d'un des condensateurs de couplage, exclut toute possibilité d'oscillation. Le dispositif d'attaque est donné par la fig. 3. Il comprend un tube de commande de la tension de polarisation négative. Normalement conducteur, ce tube est bloqué par des impulsions d'entrée négatives qui sont inversées et amplifiées sur son circuit anodique. La résistance "r_a" admet, de par sa position, un courant de repos relativement élevé qui confère, sur la grille, une grande finesse aux impulsions négatives appliquées en E. L'amplitude des impulsions d'attaque positives peut être ajustée par la résistance R_a.

Les permutations cycliques d'une chaîne selon la fig. 3 comprennent deux transitions

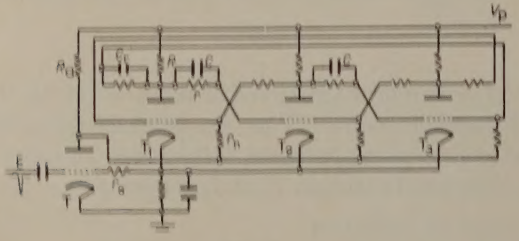

Fig. 3

"dynamiques non rétroactives" et une transition "différée". La durée des impulsions d'attaque, relatives aux deux premières transitions, doit être sensiblement égale au temps de résolution. Cette condition présente l'inconvénient d'introduire artificiellement un certain temps mort entre les impulsions, celles-ci ne pouvant se succéder à intervalles égals à leur durée.

2.5. CAPACITÉ DES CONDENSATEURS DE COUPLAGE

La valeur des capacités des circuits à couple de tubes adjacents bloqués est, par analogie de leur fonction, du même ordre de grandeur que pour l'étage binaire. Leur rôle principal, nous le rappelons, est d'élever la tension de grille du tube bloqué jusqu'à l'état de totale conduction. Cette opération exige en pratique une impulsion positive de 20 à 30 volts, transmise de l'anode d'un tube adjacent.

Il n'en est pas de même des circuits à couple de tubes adjacents conducteurs. Le rôle des condensateurs de couplage se réduit au blocage d'un tube conducteur, opération qui nécessite une dizaine de volts au maximum et s'effectue à la faveur d'un front négatif en général plus raide que ceux de signe inverse. Ces deux raisons militent en faveur d'une réduction des capacités de couplage qui peuvent être limitées entre 10 et 20 pF selon les conditions.

2.6. DYNAMIQUE DES CIRCUITS MULTISTABLES

On ne s'arrêtera qu'aux chaînes à couple de tubes adjacents conducteurs dont les transitions sont décomposables en trois phases:

(1) La tension de grille du tube initialement bloqué est élevée jusqu'au seuil de conduction.

(2) Cette même tension poursuit son élévation juqu'à atteindre le potentiel des cathodes.

(3) Recouvrement de la nouvelle tension de grille du tube bloqué par la transition.

On écrira: $T = t_1 + t_2 + t_3$.

Sans être difficile, l'analyse mathématique de ces trois phases comporte plusieurs pages de calculs symboliques qu'on nous excusera de limiter ici au commentaire des résultats:

Le blocage d'un tube de la chaîne, subséquent à la transition, commence avec la seconde phase et peut se prolonger jusqu'à la fin de la troisième sans affecter le temps de résolution. Il est possible d'ajuster la résistance R_a (fig. 3) et les éléments de couplage de manière à ce que la somme $t_2 + t_3$ soit précisément égale au temps

de décharge anodique partielle, suffisant à garantir la stabilité de la nouvelle configuration. Cette condition est convenablement satisfaite en une durée égale à deux constantes de temps du circuit anodique, ce qui permet d'écrire:

$$t_2 + t_3 \cong 2Z_b \cdot C_b \simeq 2C_b \frac{R \cdot r}{2R + r}.$$

La capacité C_b n'a pas la même valeur sur chacun des tubes de la chaîne. En se référant à la fig. 3, on voit qu'elle est maximum sur le tube T_1 (deux condensateurs anodiques), moyenne sur T_2 et minimum sur T_3.

Le temps t_1 est étroitement lié à la capacité de grille qui est, au contraire, très faible sur le tube T_1 et plus forte sur les deux autres. Cette considération permet d'écrire approximativement, pour les transitions dynamiques non rétroactives:

$$T = t_1 + t_2 + t_3 \cong 3C_b \frac{R \cdot r}{2R + r} \qquad (3)$$

où C_b est une capacité moyenne, sensiblement deux fois plus faible que celle qui intervient dans l'équation correspondante de l'étage Eccles-Jordan d'expression:

$$T \cong 1.5\, C_b \frac{R \cdot r}{R + r}.$$

La résistance anodique étant semblable, on conclu qu'il en est de même des temps de résolution, résultat qui est en accord avec l'analyse mathématique et l'expérience.

En résumé: grâce aux capacités de couplage beaucoup plus faibles nécessitées par les chaînes à couple de tubes adjacents conducteurs, leurs transitions dynamiques non rétroactives accusent un temps de résolution comparable à celui des étages Eccles-Jordan.

La décharge anodique d'un tube bloqué par une transition "différée" ne débutant qu'à la fin de l'impulsion d'attaque, prolonge d'autant le temps de résolution qui est pratiquement doublé par rapport au précédent. Nous n'exposerons pas le détail des calculs conduisant à cette conclusion dont on aura à tenir compte par la suite.

2.7. MODULATION DES IMPULSIONS

Les considérations précédentes, appliquées aux chaînes stabilisées par coupure du couplage dynamique, conduisent en toute rigueur à un temps de résolution différent pour chacune des transitions du cycle. L'efficacité optimum des impulsions d'entrée implique donc une modulation de leur durée, opération qui a été obtenue à notre entière satisfaction en polarisant la grille du tube d'attaque par l'anode des tubes T_1 et T_2 (fig. 4). Cette méthode conduit aux

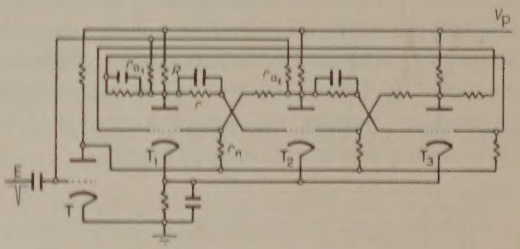

Fig. 4

meilleurs résultats acquis jusqu'ici sur des étages ternaires. Elle n'est malheureusement pas applicable aux chaînes quinaires, par suite de l'incompatibilité des conditions de modulation résultant de deux états de polarisation positive.

2.8. EN CONCLUSION

Les chaînes à couple de tubes adjacents conducteurs sont sensiblement trois fois plus stables que leur concurrente. Les chaînes ternaires de ce type permettent d'autre part la modulation des impulsions qui a pour effet d'augmenter considérablement leur stabilité dynamique. Grâce à leurs capacités de couplage très faibles, ces chaînes accusent un temps de résolution comparable à celui d'un étage Eccles-Jordan.

3. Circuits Décimaux

3.1. Les circuits décimaux composés sont en général dissociables en un étage binaire d'entrée suivit d'un étage quinaire fonctionnant à une cadence deux fois plus basse.

En raison des faibles capacités de couplage requises, le dispositif d'attaque de la fig. 3 appliqué à l'étage Eccles-Jordan, lui confère un pouvoir de résolution remarquable auquel il convient d'adapter les caractéristiques du circuit quinaire subséquent.

Les circuits multistables dont il a été question au chapitre précédent permettent de réaliser plusieurs types de décades. Faute de place, on se bornera à mentionner deux exemples particulièrement intéressants.

3.2. COUPLAGE À CYCLE QUINAIRE NATUREL

Ce circuit est basé sur la constatation que le troisième couplage dynamique d'une chaîne ternaire peut être maintenu sans compromettre sa stabilité à condition de l'effectuer par l'intermédiaire de l'étage binaire. Cette disposition particulière permet de réduire directement le cycle à cinq configurations successives.

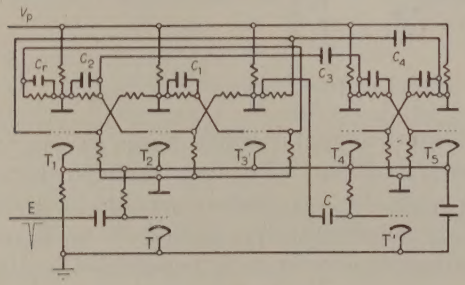

Fig. 5

La fig. 5 donne un exemple de circuit composé à cycle quinaire naturel, sans transition différée. Son fonctionnement se comprend comme suit:

Configuration initiale

T_2 et T_4 bloqués, T_1, T_3 et T_5 conducteurs.

Premiere impulsion

T_2 devient conducteur et par C_1, bloque T_3.

Deuxième impulsion

T_3 devient conducteur entraînant par C la permutation de l'étage binaire et, par C_3, le blocage de T_2.

Troisième impulsion

T_2 devient conducteur et, par C_1, bloque T_3.

Quatrième impulsion

T_3 devient conducteur d'où nouvelle permutation de l'étage binaire et, par C_4, le blocage de T_1.

Cinquième impulsion

T_1 devient conducteur et, par C_2, ferme le cycle en blocant T_2.

La quatrième transition de l'étage binaire transmet une impulsion positive sur la grille du tube conducteur T_2. La légère chute de tension anodique de ce dernier pourrait alors entraîner le blocage intempestif de T_3. Le condensateur C_r, de faible capacité, évite cette perturbation en superposant une impulsion positive à celle de signe inverse transmise de l'anode du tube T_2.

La symétrie de ce type de circuit est suffisante pour pouvoir se dispenser de moduler les impulsions d'entrée. Le temps de résolution est faible et varie peu au cours du cycle.

Equipé de transistors, ce circuit s'est avéré particulièrement intéressant. Les valeurs numériques des éléments de construction sont alors, bien entendu, totalement différentes.

3.3. RÉTROCOUPLAGE SUR LE TUBE D'ATTAQUE

La combinaison plaçant l'étage binaire avant la chaîne ternaire est seule susceptible de permettre l'utilisation rationnelle de l'étage d'entrée à condition toutefois que le temps mort consécutif à la rétroaction soit fortement réduit.

Une heureuse solution consiste à rétrocoupler sur la grille du tube d'attaque contrôlant la tension négative de l'étage binaire. La double permutation est ainsi obtenue en un temps minimum, sans surcharge appréciable des circuits (fig. 6).

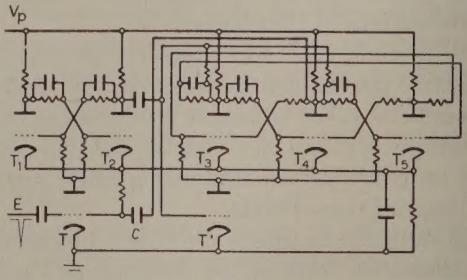

Fig. 6

La faible capacité du condensateur de rétrocouplage (5pF) n'entraîne qu'une surcharge anodique insignifiante du tube T_4. La consommation de courant est donc maintenue à sa valeur normale.

Les différentes configurations se succèdent de la manière suivante:

Etat initial

T_2, T_5 bloqués, T_1, T_3 et T_4 conducteurs.

Première impulsion

T_1, T_3 bloqués, T_2, T_4 et T_5 conducteurs.

Deuxième impulsion

T_2, T_3 bloqués, T_1, T_4 et T_5 conducteurs.

Troisième impulsion

T_1, T_4 bloqués, T_2, T_3 et T_5 conducteurs.

Quatrième impulsion

T_2, T_4 bloqués, T_1, T_3 et T_5 conducteurs.

Cinquième impulsion

Fait intervenir le rétrocouplage.

Configuration transitoire: T_1, T_5 bloqués.

Le front anodique négatif de T_4 prolonge l'impulsion d'entrée du tube d'attaque de l'étage binaire qui subit une seconde permutation.

Configuration définitive:
T_2, T_5 bloqués, T_1, T_3 et T_4 conducteurs, disposition qui s'identifie à l'état initial.

3.4. STABILITÉ DES CIRCUITS QUINAIRES

Le circuit quinaire détermine la sécurité de fonctionnement de la décade qu'il compose. Cette qualité, se prête mal à une définition analytique mais dépend largement de la stabilité dynamique qu'il est possible d'évaluer expérimentalement en déséquilibrant artificiellement le circuit par sa ligne de remise à zéro. Les cathodes sont, à cet effet, distribuées en deux groupes dont on peut modifier la tension relative et comparer l'écart maximum obtenu sans perturbation du fonctionnement à la tension moyenne de polarisation négative.

La notation: $X\%/Y\%$, indique le déséquilibre maximum mesuré dans un sens ($X\%$) puis dans l'autre ($Y\%$).

(a) Décade binaire de référence du type R.C.A.: 10.6%/10.6%.

(b) Chaîne quinaire à couple de tubes adjacents bloqués: 2.3%/2.3%.

(c) Circuit quinaire composé à couple de tubes adjacents bloqués: 2.3%/2.3%.

(d) Chaîne quinaire à couple de tubes adjacents conducteurs: 10%/5.6%.

(e) Circuit composé à cycle quinaire naturel: 10%/18.5%.

(f) Circuit quinaire composé à couple de tubes adjacents conducteurs:

(1°) Rétrocouplage classique: 18%/20.4%.

(2°) Rétrocouplage sur tube d'attaque: 18%/20.4%.

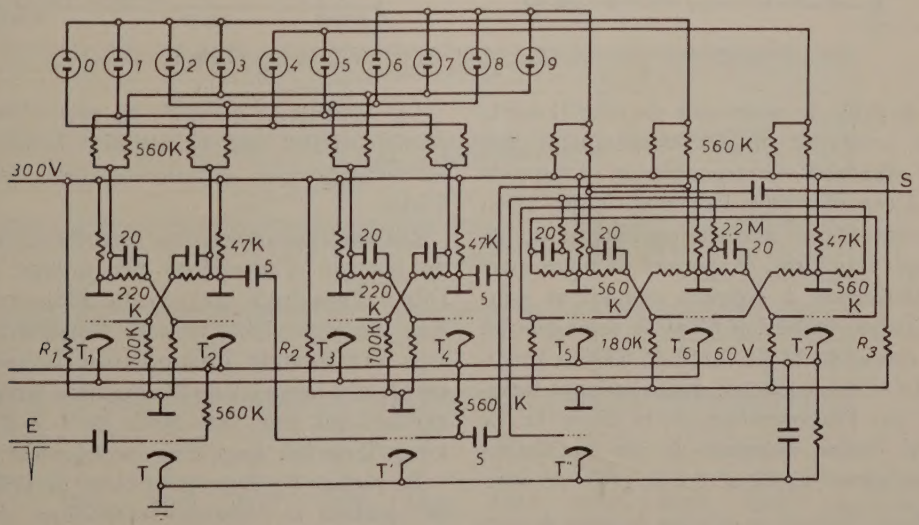

Fig. 7

Ces résultats confirment la supériorité des circuits composés à couple de tubes adjacents conducteurs.

La fig. 7 donne le schéma complet d'une décade composée à rétrocouplage sur tube d'attaque. Elle se caractérise par une fréquence d'entrée qui, à consommation égale, est environ 3 fois plus élevée que pour une décade binaire classique tandis que les éléments de construction, notamment les condensateurs, sont légèrement moins nombreux et la stabilité presque double.

4. Dispositif d'Abaissement du Temps de Résolution[6])

4.1. Le dispositif en question (fig. 8) est spécifiquement applicable à la numération d'impulsions de nature statistique dont il élimine pratiquement les pertes.

Les impulsions positives d'entrée sont appliquées à la grille de commande du tube H sur la capacité anodique duquel s'accumulent des charges standard correspondantes. L'heptode choisie à cet effet offre l'avantage d'une résistance interne élevée, nécessaire à l'invariance de la charge standard, et permet d'autre part l'autopolarisation à courant cathodique constant. Chaque impulsion d'entrée provoque un même accroissement de chute de tension anodique, suivi d'une décharge quasi linéaire, interrompue par l'invervention de la diode D. Ce processus donne naissance à des impulsions "intermédiaires" appliquées à la grille de commande du tube T qui contrôle le fonctionnement du multivibrateur M. Au repos la triode de blocage T est conductrice tandis que le multivibrateur M est bloqué. L'apparition d'une impulsion intermédiaire de signe négatif bloque T alors que M se met à osciller en produisant autant d'impulsions de sortie qu'il s'était accumulé de charges standard.

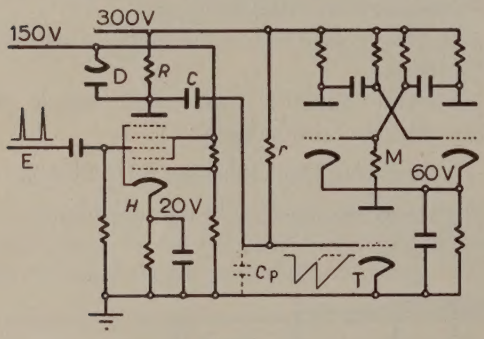

Fig. 8

L'étage Eccles-Jordan, attaqué par un tube de contrôle de la tension négative, constitue une variante de multivibrateur parfaitement adaptée à l'application envisagée. Chaque impulsion d'entrée doit alors entraîner une seule transition du multivibrateur qui devient de ce fait le premier étage de démultiplication. La décade de la fig. 7 peut, sur ce principe, être attaquée directement à partir du tube d'accumulation.

La présence d'un amplificateur A entre le tube d'accumulation H et la triode de blocage T (fig. 9) améliore la réponse du dispositif.

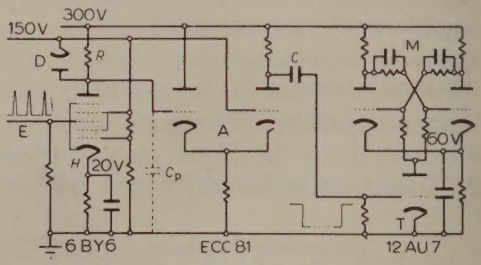

Fig. 9

On appellera "groupe" un ensemble d'impulsions telles que la capacité anodique ne se décharge pas entièrement entre chacune d'elles.

Les conditions de réponse correcte, en fonction du nombre d'impulsions par groupe, à fait l'objet d'une étude approfondie qu'il serait trop long d'exposer ici. Précisons simplement que, sans amplificateur intermédiaire, la résolution est assurée jusqu'à 2 ou 3 impulsions par groupe, nombre qui peut être élevé de 1 à 2 unités lorsqu'il est fait usage d'un amplificateur.

Le réglage du dispositif s'opère de préférence en ajustant la résistance cathodique du tube d'accumulation.

[6]) R. Favre, Dispositif de réduction du temps de résolution, Helv. Phys. Acta **27** (1954) 683–689.

4.2. ERREURS DE MESURE

Le temps de résolution propre d'un multivibrateur bloqué de type monostable (flip-flop) est égal à sa période d'oscillation tandis qu'il se réduit à la demi période dans le cas d'un multivibrateur bloqué de type bistable (étage binaire).

Soient: N, la fréquence moyenne des impulsions
Δt, le temps de résolution du multivibrateur.

Ce dernier temps est égal à la durée de l'impulsion intermédiaire correspondant à une seule charge standard et intervient à ce titre dans l'expression de la probabilité de formation des groupes.

Le produit $\Delta t \cdot N$ étant toujours, dans les cas qui nous occupent, une faible fraction de l'unité, les problèmes de nature statistique se réfèrent à la formule de Poisson:

$$P(x) = \frac{e^{-\Delta t \cdot N} (\Delta t \cdot N)^x}{x!} .$$

Dans laquelle $P(x)$ est la probabilité d'obtenir x impulsions dans l'intervalle de temps Δt.

La probabilité de génération d'un groupe d'ordre quelconque résulte de la somme des probabilités de formation de ce groupe selon les divers processus indépendants possibles.

On montre que:

$P(1)$ exprime la perte statistique d'impulsions d'un démultiplicateur de temps de résolution Δt.

$P(2) + P(1)^2$ exprime la perte statistique d'impulsions du même démultiplicateur précédé d'un dispositif permettant la résolution des groupes de deux impulsions.

$P(3) + 2 \cdot P(2) \cdot P(1) + P(1)^3$ exprime enfin la perte statistique d'impulsions d'un démultiplicateur semblable, précédé d'un dispositif de résolution des groupes de trois impulsions.

En tenant compte que $e^{-\Delta t \cdot N} \cong 1$, les expressions respectives se réduisent aux formes suivantes:

$$P(1) = \Delta t \cdot N$$
$$P(2) + P(1)^2 = 3/2 \, (\Delta t \cdot N)^2$$
$$P(3) + 2 \cdot P(2) \cdot P(1) + P(1)^3 = 13/6 \, (\Delta t \cdot N)^3 .$$

On a établi à la figure 10 les courbes de pertes statistiques en fonction du taux de comptage. L'ordre le plus élevé des groupes résolus est porté en paramètre. Les courbes relatives à un temps de résolution quelconque sont obtenues

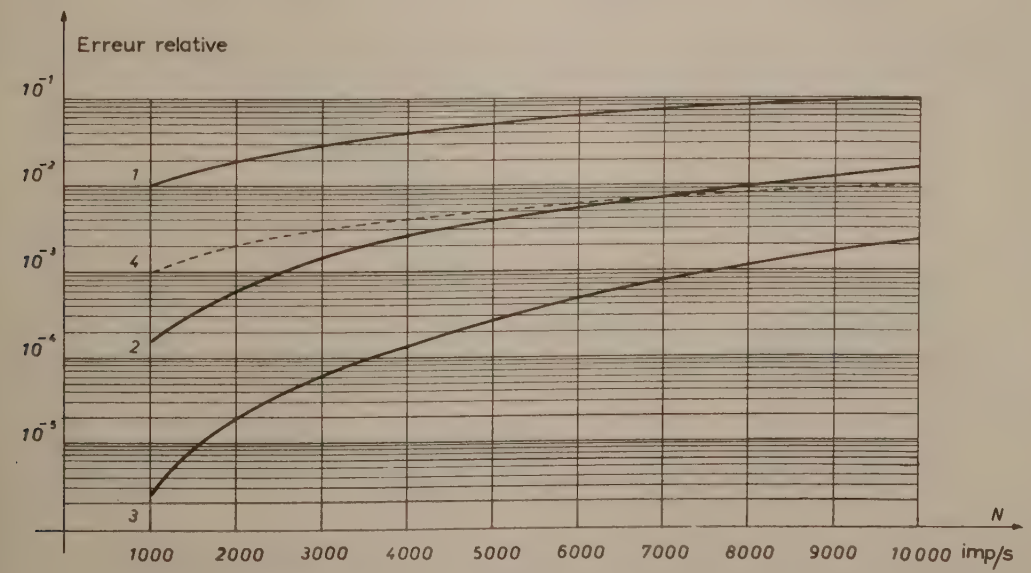

Fig. 10

par translation, à un niveau proportionnel à ce dernier, des fonctions données sur le graphique (exemple, courbes 1 et 4). On arrive à la conclusion que pour Δt compris entre 5 et 10 μsec, et un taux de comptage maximum de 10000 imp/sec, la résolution des groupes de plus de 3 impulsions est inutile si le temps mort de la source n'est pas inférieur à 0.1 μsec, d'où l'intérêt du dispositif, même sans amplificateur.

4.3. APPLICATIONS

Le dispositif proposé permet la construction de démultiplicateurs électroniques simples, stables et de faible consommation bien que doués, à l'égard d'impulsions statistiques, d'un temps de résolution pratiquement limité à celui des circuits de mise en forme.

La résolution des groupes de deux impulsions étant suffisante dans la plupart des cas, il est souvent possible de supprimer l'amplificateur différentiel. Le dispositif auxiliaire se réduit alors à l'heptode H, la diode D et quelques autres éléments de moindre importance (fig. 8). Le multivibrateur bloqué constitue le premier étage de démultiplication et comme tel ne figure pas en supplément.

Lorsque les impulsions de détecteurs ou autres sources travaillant en parallèle doivent être dénombrées par un même appareil, il est possible d'accumuler les charges standard par autant de voies distinctes qu'il y a de sources. Le temps de résolution par rapport aux impulsions d'origines différentes est pratiquement annulé.

L'emploi d'un multivibrateur bloqué monostable, donc indépendant des étages de démultiplication, se justifie dans plusieurs cas dont nous suggérons quelques exemples:

(1) Pour l'équipement d'un démultiplicateur existant, sans avoir à modifier sa structure interne.

(2) Pour précéder les démultiplicateurs à tubes de numération décimaux (tubes Philips, trochotrons, dékatrons, etc.).

(3) Pour l'attaque d'un numérateur mécanique soumis à des impulsions de nature statistique.

L'application la plus importante de ce procédé est probablement celle qu'on en peut faire à l'enregistrement d'impulsions périodiques à haute fréquence dont le principe est donné par la suite.

L'exposé de ce dispositif accessoire termine la partie de notre travail consacrée plus particulièrement à la rationalisation des procédés de numération.

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LE TEST DES BLOCS DE L'ELECTRO-AIMANT DU SYNCHROTRON DE SACLAY

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After a brief description of the synchrotron magnet and the effects of the field inhomogeneities, we describe the principle of the stacking procedure the purpose of which is minimising these effects.

To carry out this method a programm of magnetic measurements was set up. We give its principle practical set up and main results.

The practical way for determining the azimuthal location of the blocks is developed. At last we estimate the gain of the operation with respect to a random distribution.

1. Constitution de l'Aimant et Inhomogénéités Azimutales

Le fonctionnement du synchrotron exige la présence d'une induction magnétique dans tout le volume annulaire occupé par les particules au cours de leurs oscillations autour de l'orbite d'équilibre. L'induction doit satisfaire à certaines lois de variation dans le temps et dans l'espace.

L'orbite d'équilibre est formé de 4 quarts de circonférence de 8.45 m de rayon, séparés l'un de l'autre par des sections droites de 4 m de longueur (fig. 1). L'induction possède sa pleine valeur dans les quarts de circonférence (ou quadrants). Elle doit s'annuler dans les sections droites; en fait, elle s'y réduit aux fuites magnétiques.

L'électro-aimant qui engendre l'induction est constitué d'éléments semblables (ou blocs) disposés le long de l'orbite d'équilibre. La fig. 2 représente le profil d'un de ses éléments. Le bloc proprement dit, ou culasse, est muni de pièces polaires indépendantes. Chaque bloc est un assemblage de 14 tôles de 10 mm d'épaisseur nominale et de quelques tôles de 0.9 mm d'épaisseur nominale; l'épaisseur réelle de fer est, au minimum de 145 mm.

Chaque quadrant comprend 71 de ces blocs et couvre un arc légèrement inférieur à 90°; le flux de fuite équivaut à la présence d'un demi-bloc à

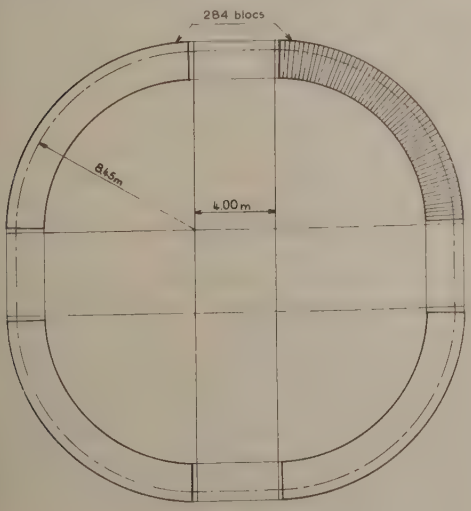

Fig. 1

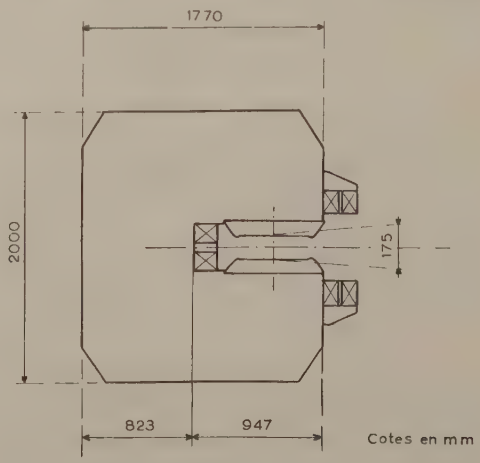

Fig. 2

chaque extrémité et donne au quadrant une ouverture efficace de 90°, de sorte que l'électro-aimant est équivalent, en ce qui concerne le mouvement des particules, à l'assemblage de 288 blocs disposés régulièrement sur une circonférence.

Les tôles, dont la composition chimique répond à des tolérances bien définies, ont été découpées, recuites et assemblées selon un processus théoriquement invariable. Néanmoins, les blocs ne sauraient être rigoureusement identiques. Il en résulte un défaut d'homogénéité dans la répartition azimutale des caractéristiques magnétiques de l'aimant. Une étude préalable sur modèle a permis de conclure que le bloc proprement dit (culasse), en tant qu'élément du circuit magnétique, ne possède une influence perceptible que sur l'induction B_0 au centre de l'entrefer, les autres grandeurs magnétiques (et, en particulier, l'indice n) étant déterminées par les pièces polaires.

Le défaut d'homogénéité des blocs se traduit donc surtout par une inégale répartition azimutale de l'induction B_0, provoquant ainsi une déformation de la trajectoire fermée dont l'excursion (ou écart par rapport à la circonférence idéale) peut être évaluée de la facon suivante.

L'induction B correspondant à une valeur fixée du courant d'excitation est une fonction $B(\theta)$ de l'angle azimutal θ et peut être développée en série de Fourier.

$$B(\theta) = B_0 + a_1 \sin\theta + \beta_1 \cos\theta + \cdots + a_m \sin m\theta + \beta_m \cos m\theta + \cdots \quad (1)$$

avec

$$a_m = \frac{2}{N}\sum_{k=1}^{N} B_k \sin m\theta_k \quad \text{et} \quad \beta_m = \frac{2}{N}\sum_{k=1}^{N} B_k \cos m\theta_k \quad (2)$$

N est le nombre total de blocs, B_k et θ_k sont les valeurs de B et de θ correspondant au bloc numéroté k à partir d'une origine quelconque.

Dans le développement en série de Fourier, l'amplitude de l'harmonique d'ordre m est:

$$b_m = \sqrt{a_m^2 + \beta_m^2} \ . \quad (3)$$

L'amplitude maximum de l'excursion radiale de la trajectoire fermée provoquée par cet harmonique est (voir[1]):

[1]) Courant et Blachman, Rapport interne Brookhaven National Laboratory, 5 Décembre 1949.

$$X_m = \frac{b_m}{B_0}\frac{R_0}{m^2 - Q_H^2} \quad (4)$$

formule dans laquelle R_0 est le rayon de l'orbite d'équilibre et Q_H le nombre d'oscillations bétatron horizontales par tour. Pour le Synchrotron de Saclay, $R_0 = 8.45$ m et $Q_H = 0.72$.

Nous allons chercher à diminuer l'amplitude $X = \Sigma_m X_m$ afin de diminuer le nombre de particules qui sortiraient de la zone utile du champ et qui seraient perdues. Nous sommes ainsi conduits à réduire $b_m/(m^2 - Q_H^2)$, donc à réduire b_m pour les valeurs les plus faibles de m, c'est-à-dire à rendre a_m et β_m négligeables pour m petit.

2. Principe de l'Elimination des Harmoniques

2.1. ELIMINATION D'UN HARMONIQUE

Comme nous l'avons dit plus haut, l'électro-aimant est équivalent à l'assemblage de N blocs disposés régulièrement sur une circonférence. Désignons par θ_0 l'angle $2\pi/N$; l'angle θ_k est égal à $k\theta_0$ et les formules (2) s'écrivent:

$$\frac{N}{2} a_m = B_1 \sin m\theta_0 + B_2 \sin 2m\theta_0 + \cdots + B_i \sin im\theta_0 + \cdots + B_j \sin jm\theta_0 + \cdots + B_N \sin 2\pi m$$

$$\frac{N}{2} \beta_m = B_1 \cos m\theta_0 + B_2 \cos 2m\theta_0 + \cdots + B_i \cos im\theta_0 + \cdots + B_j \cos jm\theta_0 + \cdots + B_N \cos 2\pi m \ .$$

Nous allons chercher à annuler a_m et β_m en groupant les termes deux par deux et en annulant séparément chaque groupe de deux termes. Nous voulons donc que soient vérifiés $\frac{1}{2}N$ systèmes d'équations tels que:

$$\begin{aligned} B_i \sin im\theta_0 + B_j \sin jm\theta_0 &= 0 \\ B_i \cos im\theta_0 + B_j \cos jm\theta_0 &= 0 \ . \end{aligned} \quad (5)$$

Il est clair que les égalités:

$$\begin{cases} B_i = B_j \\ mi\theta_0 - mj\theta_0 = (2p+1)\pi \end{cases} \quad (6)$$

où p est un entier positif ou nul, résolvent la question.

Si donc nous associons deux par deux les blocs ayant une même induction pour un courant d'excitation donné et si nous les disposons de telle sorte que leur écart angulaire $i\theta_0 - j\theta_0$ soit un multiple impair de π/m, nous annulons a_m et β_m, donc l'harmonique b_m d'ordre m.

Par exemple, nous annulons l'harmonique fondamental ($m = 1$) en adoptant pour écart angulaire π, c'est-à-dire en opposant diamétralement les blocs ayant môme induction.

2.2. ELIMINATION D'UN GROUPE D'HARMONIQUES

La condition d'angle des équations (6) peut être satisfaite pour m valeurs distinctes de p, c'est-à-dire pour m écarts angulaires distincts, à savoir: π/m, $3\pi/m$, ..., $(2m - 1)\pi/m$.

Or l'entier m peut être mis, d'une seule manière, sous la forme $m = 2^h(2q + 1)$.

Considérons tous les entiers m pour lesquels, dans cette décomposition, l'exposant h a la même valeur h_0, q ayant les valeurs 0, 1, 2... Pour celui de ces entiers qui correspond à $q = q_0$, la condition d'angle est satisfaite pour les écarts angulaires

$$\frac{(2p + 1)\,\pi}{2^{h_0}(2q_0 + 1)}$$

et en particulier, puisque p prend toutes les valeurs entières, pour l'écart angulaire

$$\frac{(2q_0 + 1)\,\pi}{2^{h_0}(2q_0 + 1)} = \frac{\pi}{2^{h_0}}\,.$$

Ceci est vrai quel que soit q_0.

Si donc nous associons deux par deux les blocs ayant une même induction pour un courant d'excitation donné, et si nous les disposons de telle sorte que leur écart angulaire $i\theta_0 - j\theta_0$ soit égal à $\pi/2^{h_0}$, nous annulons simultanément les harmoniques b_m d'ordre $m = 2^{h_0}(2q + 1)$ avec $q = 0, 1, 2...$ Par exemple, avec $h_0 = 2$ (l'angle $\pi/4$), nous annulons les harmoniques d'ordre 4, 12, 20...

2.3. ELIMINATION SIMULTANÉE DE PLUSIEURS GROUPES D'HARMONIQUES

Considérons maintenant tous les entiers m pour lesquels, dans la décomposition envisagée ci-dessus, l'exposant h prend l'ensemble des valeurs inférieures ou égales à h_0. A chaque valeur de h correspond un angle $\pi/2^h$ qui assure l'annulation des harmoniques d'ordre $m = 2^h(2q + 1)$ avec $q = 0, 1, 2...$ Or, $\pi/2^h$ est égal au produit de $\pi/2^{h_0}$ par une puissance de 2, puisque $h = h_0$.

Si donc nous formons des groupes de 2^{h_0+1} blocs ayant même induction pour un courant d'excitation donné et si nous disposons les blocs de chaque groupe aux sommets d'un polygone régulier de 2^{h_0+1} côtés (polygone dont l'angle au centre est égal à $2\pi/2^{h_0+1} = \pi/2^{h_0}$), nous pouvons, pour chaque valeur de h inférieure ou égale à h_0, associer les blocs deux par deux dans chaque groupe pour former tous les angles $\pi/2^h$ qui annulent les harmoniques d'ordre $2^h(2q + 1)$.

Par exemple, avec $h_0 = 2$, nous formons des groupes de 8 blocs ayant même induction et nous les disposons aux sommets d'un octogone régulier; nous annulons alors:

les harmoniques d'ordre $2^0(2q + 1) = 2q + 1$, puisque deux blocs écartés de $\pi/2^0 = \pi$ sont identiques;
les harmoniques d'ordre $2(2q + 1)$ puisque deux blocs écartés de $\pi/2$ sont identiques;
les harmoniques d'ordre $4(2q + 1)$ puisque deux blocs écartés de $\pi/4$ sont identiques.

Ainsi, dans cet exemple, les premiers harmoniques annulés sont ceux d'ordre 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12... et les premiers harmoniques non annulés sont ceux d'ordre 8 et 16.

Cette méthode suppose que le nombre total de blocs est une puissance de 2; elle suppose aussi qu'il est possible de former des groupes de 2^{h_0+1} blocs ayant même induction. Nous indiquerons, après les résultats de mesure, comment peut se faire l'adaptation de la méthode lorsque ces conditions ne sont pas réalisées.

3. Principe des Mesures Magnetiques

Dans le synchrotron, l'induction varie en fonction du temps suivant la courbe représentée fig. 3. La partie utile du cycle, au cours de

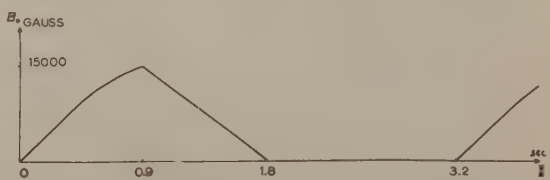

Fig. 3. La vitesse de montée de l'induction est de 20 000 gauss par seconde au début du cycle. Une régulation assure la constance de la vitesse de descente.

laquelle se produit l'accélération des particules, est la partie ascendante.

Nous avons vu que l'élimination des harmoniques suppose la connaissance de l'induction dans chaque bloc pour un courant d'excitation donné. A cette fin, nous avons fait subir à chaque bloc un cycle identique à celui qu'il subira pendant le fonctionnement du synchrotron; et nous avons fait des mesures de l'induction pendant la montée du cycle, aux instants les plus importants, ceux qui correspondent approximativement:

à l'injection des particules (300 gauss);
- à l'expansion complète du faisceau (600 et 1000 gauss);
- à la proportion minimum d'ampères-tours consommés dans la culasse par rapport aux ampères-tours totaux (7000 gauss);
- à la saturation de l'acier (12 000, 14 000, 15 000 gauss).

Les chiffres entre parenthèses se rapportent à l'induction dans l'entrefer; l'induction dans la culasse est plus élevée, dans un rapport voisin de 4/3.

3.1. MESURES DYNAMIQUES

La méthode de mesure consiste à placer dans l'entrefer une bobine dans laquelle la variation de flux induit une tension proportionnelle à $\frac{dB}{dt}$. Cette tension est intégrée par un procédé électronique[2,3]). On en déduit une valeur de l'induction, dite valeur dynamique, à laquelle il convient d'ajouter une constante d'intégration: l'induction rémanente. Cette dernière doit être mesurée séparément.

L'erreur totale tolérée dans ces mesures est 1/1000. Le calcul de l'excursion de l'orbite fermée, provoquée par des inhomogénéités azimutales ayant cette valeur, montre que la perte d'ouverture est alors de 5 mm environ, ce qui est faible par rapport à l'extension radiale de la zone utile de la chambre (370 mm).

[2]) J. Taieb, H. Guillon, A. Gabet et J. Mey, Appareillage de Mesure d'un Champ Magnetique Variable, Onde Electrique (Novembre 1955) 1076–1083.

[3]) Article de J. Taieb à paraître.

Il est difficile de mesurer directement une induction variable avec cette précision. Nous avons eu recours, pour les valeurs dynamiques, à une mesure relative consistant à comparer l'induction B_T dans le bloc à tester à l'induction B_R dans un bloc, toujours le même, pris comme référence. Plus exactement, la mesure a porté sur $\Delta B = B_T - kB_R$, k étant un coefficient fixe voisin de 0.9. Ainsi, ΔB est de l'ordre de 1/10 de B_T. L'appareillage dont nous disposions permettait de mesurer les inductions à 1/100 près; nous avons donc obtenu les valeurs dynamiques à 1/1000 près.

Nous nous étions assurés que les propriétés magnétiques du bloc de référence ne devraient pas évoluer au cours de l'ensemble des tests, en vérifiant, par une étude préliminaire sur modèle, que l'induction dans un bloc quelconque, soumis à un grand nombre de cycles identiques (30 000), ne varie pas plus de 1/1000 de sa valeur.

Néanmoins, un bloc témoin ne faisant pas partie de l'électro-aimant du synchrotron a été mesuré à plusieurs reprises au cours de la période des tests, chaque fois qu'une vingtaine de blocs avaient été testés. Pour que le principe des mesures relatives soit légitime, il fallait que les résultats concernant ce bloc témoin ne laissent pas apparaître une variation monotone au cours du temps, supérieure à 1/1000.

3.2. MESURE DE L'INDUCTION RÉMANENTE

L'induction rémanente est de l'ordre de 1/20 de l'induction totale dans le cas le plus défavorable, celui de l'injection (300 gauss). Il suffit donc de la mesurer avec une erreur maximum de l'ordre de 1/100. Une mesure absolue utilisant un magnétomètre spécial[3]) a suffi à nous donner une précision plus grande.

L'étude sur modèle nous avait permis de vérifier que l'induction rémanente dans l'entrefer d'un bloc se stabilise, à 1% près, dès le 3ème cycle.

3.3. AUTRES MESURES

L'influence de la pente de la partie descendante du cycle sur l'induction rémanente après le cycle avait été mise en évidence: pour le

cycle considéré, une augmentation de 10% de la vitesse de décroissance entraîne une diminution de 1% de l'induction rémanente. Ce fait nous a conduits à enregistrer $\frac{dB}{dt}$ afin de vérifier le fonctionnement de la régulation en $\frac{dB}{dt} =$ constante de la partie décroissante du cycle $B(t)$.

Une autre mesure de contrôle a été celle de l'indice moyen, valeur de $\frac{R_0}{B_0}\frac{\Delta B}{\Delta R}$ pour $\Delta R = 20$ cm, qui est lié au montage mécanique des pièces polaires sur la culasse.

4. Realisation des Mesures

4.1.

Les mesures ont été réalisées dans un électro-aimant (fig. 4) qui, outre le bloc à tester et le bloc de référence, comporte deux blocs de garde de chaque côté. Pour simplifier la construction de cet aimant, dit "hexabloc", et surtout pour faciliter la substitution des blocs à tester, la courbure de l'orbite d'équilibre n'est pas respectée et les six blocs sont parallèles. Ce n'est là qu'un mince inconvénient puisque nous savons que l'effet d'éventail n'a qu'une faible répercussion sur le flux de culasse (il modifie surtout la répartition de l'induction dans les pièces polaires et dans l'entrefer) et qu'il s'agit surtout de comparer différents blocs placés dans les mêmes conditions.

Pour effectuer la substitution des blocs à tester, on rapproche les pièces polaires l'une de l'autre et on enlève le bloc par l'arrière, la bobine d'excitation restant en place; on introduit le bloc suivant, toujours par l'arrière, puis on remet en place les pièces polaires et on ajuste la position du bloc au moyen de plusieurs vérins.

4.2. PROCÉDURE DE CONTROLE

Des dispositions de contrôle de l'appareillage de mesure ont été adoptées pour la durée des tests:

pendant la periode de mise au point

Le magnétomètre a été étalonné avec une erreur inférieure à 10^{-3}, les surfaces des bobines ont été mesurées (l'erreur étant de l'ordre de 10^{-2}) et la constante k des mesures dynamiques déterminée avec une erreur maximum de 10^{-4}.

au cours des mesures sur un bloc

La cohérence des résultats donnés par le magnétomètre était vérifiée par comparaison des valeurs de l'induction rémanente dans le bloc de référence pour différents blocs testés. Une mesure de l'induction dynamique dans le bloc de référence ($\Delta B = B_{\text{Réf.}} - kB_{\text{Réf.}}$) permettait de vérifier le bon fonctionnement de l'ensemble de l'appareillage de mesures dynamiques et de contrôler à 10^{-3} près le coefficient k.

pendant la periode de test

Les étalonnages effectués au cours de la période de mise au point ont été refaits toutes les 50 opérations de tests.

Les mesures dans le bloc témoin ont été reprises régulièrement (chaque fois que vingt blocs étaient testés), pour déceler une dérive lente ou une variation dans le dispositif de mesure.

Pour permettre la comparaison des résultats, les conditions de mesures doivent être identiques. La reproductibilité du cycle a été contrôlée par l'enregistrement de la valeur de $\frac{dB}{dt}$. Le passé magnétique pouvant influencer les mesures, celles-ci ont été effectuées dans les mêmes conditions: 30 et 50 cycles d'aimantation précédant respectivement les mesures dynamiques et de rémanent.

Dans le but de mettre en évidence une erreur systématique due à un opérateur, toutes les mesures ont été faites par chacun des deux expérimentateurs. Ainsi, l'induction dynamique de chaque bloc est la moyenne des résultats de 20 cycles, chaque opérateur faisant dix mesures. De plus, les valeurs importantes (celles correspondant à l'injection et la saturation) étaient affichées deux fois sur les dispositifs de lecture. L'induction rémanente est la moyenne des résultats de six mesures (3 par opérateur).

Lorsqu'un test était terminé, un contrôleur vérifiait la cohérence des valeurs mesurées et la présence de toutes les indications nécessaires au calcul.

Les résultats de la mesure étaient consignés pour chaque grandeur (ΔB, n, rémanent) dans un cahier à feuilles détachables, chaque opérateur ayant son propre cahier. Les pages étaient imprimées, l'expérimentateur n'ayant à inscrire que les résultats de lecture.

De même, on se servait pour les calculs de feuilles imprimées où le calculateur reportait certains résultats intermédiaires et les résultats finaux. On utilisait des machines à calculer à bande imprimée; les bandes étaient conservées et permettaient de retrouver les erreurs éventuelles. De plus, chaque calcul de bloc était effectué entièrement par deux calculateurs différents.

4.3. DURÉE DES TESTS

Au début de l'expérimentation, la durée d'un test était de 3 heures (1h 45 mn pour les mesures, 1h 15 mn pour la mise en place). Trois blocs étaient testés par jour. Par la suite, cette durée s'est trouvée réduite à 2 heures (respectivement 1h 15 mn et 45 mn), ce qui permettait de tester 4 ou 5 blocs par jour. Le temps nécessaire à un calcul était de 1h 30 mn à 2h, soit 3 à 4 heures pour le calcul complet relatif à un bloc.

Après une période de 1 mois et demi de mise au point et de contrôle de l'appareillage, la totalité des tests a été effectuée en 4 mois, dont 5 semaines de travail en double équipe (6 à 8 blocs testés par jour). Un mois a été consacré à l'étude de la répartition des blocs.

La responsabilité des tests était confiée à deux ingénieurs; une équipe comprenait deux agents techniques pour les mesures et trois compagnons pour la mise en place du bloc. Un ingénieur et un agent technique étaient chargés du dépannage et de l'entretien de tout le matériel de mesure. La traduction des résultats de mesure en paramètres de groupage était assurée par un bureau de calcul composé de 4 calculateurs.

5. Resultats Experimentaux

5.5. LE BLOC TÉMOIN

Le bloc témoin dont il a été question plus haut (au paragraphe "Mesures dynamiques") a été mesuré 13 fois au cours de l'ensemble des tests. Les valeurs successivement trouvées pour son induction, lorsque la valeur dynamique B_R du bloc de référence est 300 gauss, sont reportées fig. 5. Elles sont réparties autour d'une droite moyenne (droite des moindres carrés) dont la pente correspond à un écart de 0.2. gauss entre la première et la dernière mesure. Cette valeur

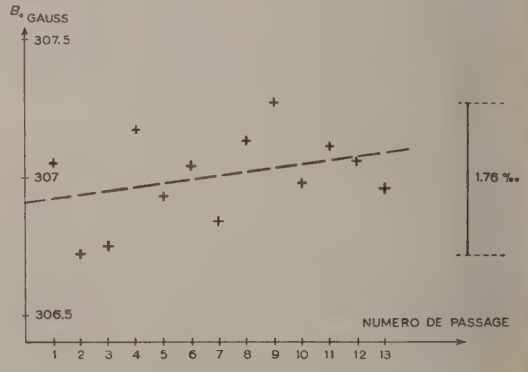

Fig. 5

étant inférieure à 1/1000, nous pouvons considérer que l'emploi des mesures relatives est justifié.

La dispersion des 13 mesures est affectée d'un écart quadratique moyen de 0.15 gauss, soit 0.5/1000. Cette dispersion mesurée tient compte de toutes les causes de non-reproductibilité: position non strictement identique du bloc, dérive lente des caractéristiques magnétiques du bloc témoin, irrégularités de l'appareillage de mesure. Bien que le nombre de 13 mesures ne soit pas très grand, nous prendrons la valeur 0.15 gauss comme écart quadratique moyen de l'erreur de mesure sur un bloc pour $B_R = 300$ gauss.

5.2. LES BLOCS NORMAUX

La figure 6 représente les variations de l'induction de chacun des blocs, dans leur ordre de passage dans l'hexabloc.

On voit que l'induction rémanente accuse des écarts importants, d'amplitude $\pm$ 10%, et l'induction à l'injection des écarts de $\pm$ 4/1000. Pour une induction B_R de 7000 gauss dans le bloc de référence, la dispersion est faible et les écarts sont de l'ordre de $\pm$ 1/1000; à la satura-

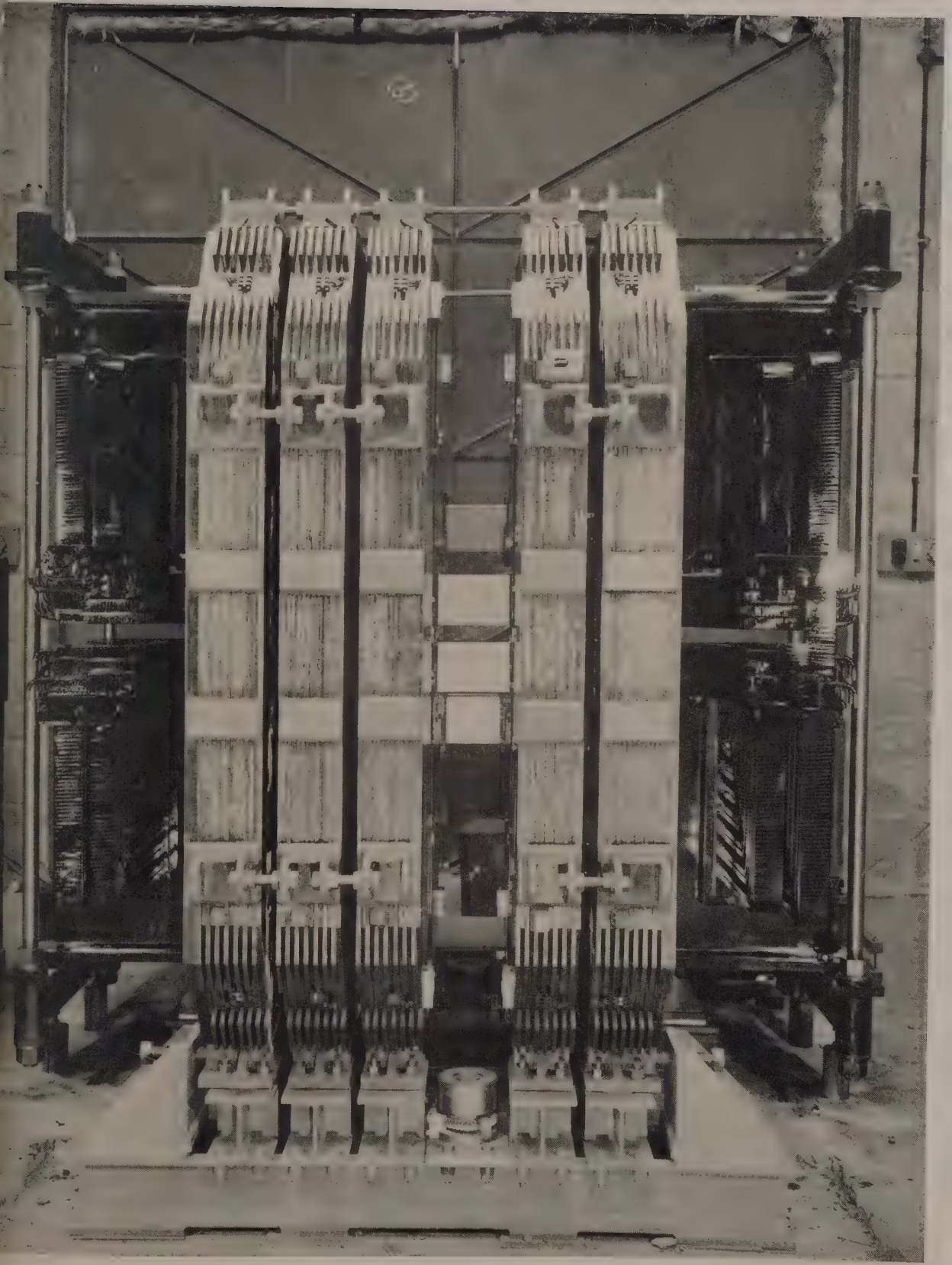

Fig. 4. Vue arrière de l'hexabloc – Le bloc à tester est retiré; on distingue les deux vérins de positionnement vertical et les huit vérins de positionnement latéral.

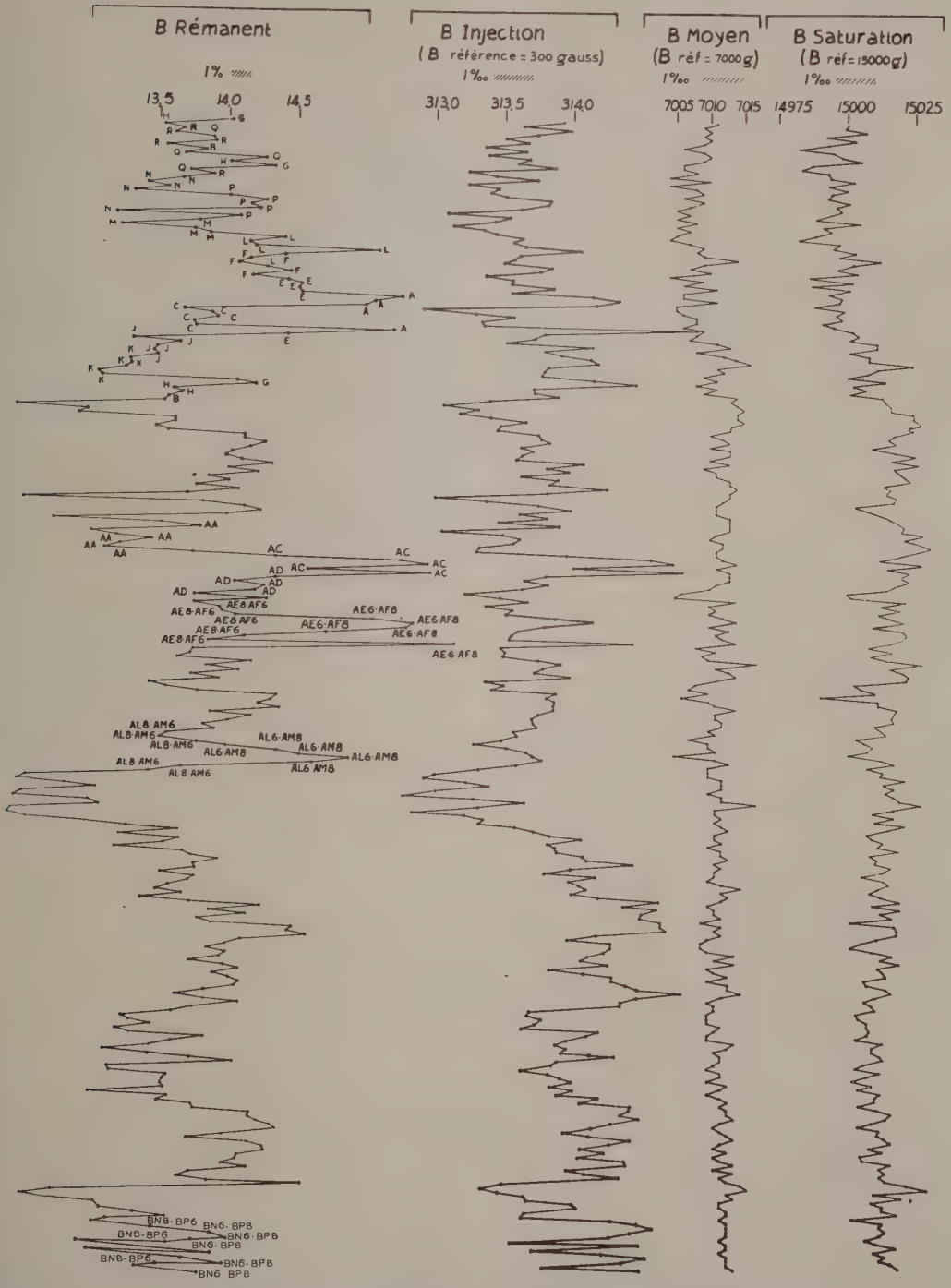

Fig. 6. Pour ne pas surcharger la figure, on n'a inscrit les lettres caractéristiques du recuit que pour certains blocs. La valeur de l'induction dans le bloc de référence est la valeur dynamique.

tion (15 000 gauss), la dispersion est un peu plus élevée.

5.3. INFLUENCE DE CERTAINS PARAMETRES

Les tôles de 10 mm ont été recuites par piles de 70 tôles (l'équivalent de 5 blocs). Chaque pile était repérée par une ou deux lettres. Sur la fig. 5, on a inscrit, près de certaines valeurs de rémanent, la ou les lettres caractérisant les blocs du point de vue du recuit. Ainsi, le bloc marqué AC est constitué de 14 tôles de la pile AC, le bloc marqué BN8BP6 de 8 tôles de la pile BN et 6 tôles de la pile BP. On constate que les blocs repérés de la même manière ont des inductions rémanentes sensiblement égales.

Il n'a pas été possible d'établir une corrélation entre l'induction rémanente et la composition chimique de l'acier; d'ailleurs, les tôles d'un même bloc proviennent de différentes coulées d'acier (4 en moyenne) et il est difficile de caractériser un bloc par une composition déterminée.

Par contre, le recuit proprement dit semble avoir une influence sur l'induction rémanente, probablement par l'intermédiaire de la température du four. Cependant, nous n'avons pas pu établir une relation précise entre l'induction rémanente et les paramètres du recuit: temps de montée, durée de refroidissement, température de stabilisation, etc...

L'induction à 7000 gauss est en liaison directe avec la hauteur d'entrefer, la consommation d'ampères-tours dans la culasse étant très faible et pratiquement nulle. La dispersion des hauteurs d'entrefer de l'ensemble des blocs est infime; les écarts sont de l'ordre de $\pm$ 0.2/1000; la dispersion des valeurs de l'induction est uniquement celle due aux mesures.

A la saturation, la consommation de culasse varie en fonction de la section de métal, c'est-à-dire de l'épaisseur du bloc. Les écarts de l'induction sont un peu supérieurs à ceux dûs aux mesures; on pourrait voir, en comparant les courbes de B et d'épaisseur des blocs, que les valeurs les plus élevées correspondent, comme on peut s'y attendre, aux plus grandes épaisseurs.

5.4. CHOIX D'UNE VALEUR DE L'INDUCTION DE RÉFÉRENCE

La comparaison des résultats à différents instants du cycle montre une concordance entre les variations de l'induction d'un bloc à l'autre à $B_R = 300$, 600 et 1000 gauss; les variations relatives sont plus faibles à 600 gauss qu'à 300 gauss, et encore plus faibles à 1000 gauss.

Cela nous a permis de choisir la valeur $B_R = 300$ gauss pour étudier la répartition des blocs, d'autant plus que cette valeur correspond sensiblement à l'une des phases les plus importantes du cycle: l'injection. Une répartition, rendant négligeables les harmoniques à 300 gauss, les rend ipso facto négligeables à 600 gauss et à 1000 gauss, c'est-à-dire pendant toute la période critique de l'expansion maximum du faisceau.

Aux autres valeurs de l'induction, la dispersion est très voisine de celle des erreurs de mesure; nous avons donc adopté la valeur de l'induction pour $B_R = 300$ gauss comme paramètre unique dans l'étude du groupement des blocs.

La fig. 7 est une courbe de répartition des valeurs de l'induction B dans les différents blocs pour $B_R = 300$ gauss. La valeur moyenne est $B = 313.83$ gauss et l'écart quadratique moyen $\sigma_m = 0.41$ gauss, soit 1.3/1000.

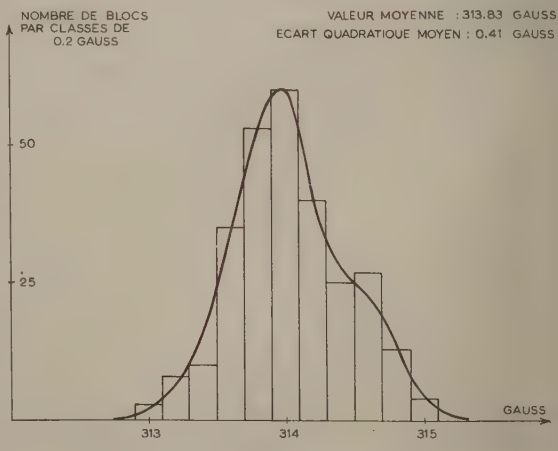

Fig. 7

Les valeurs mesurées de B sont affectées, nous l'avons vu, d'une imprécision dont l'erreur quadratique moyenne est $\sigma_e = 0.15$ gauss; l'écart quadratique moyen réel σ_r est donné, en

considérant que les répartitions sont gaussiennes par $\sigma_m^2 = \sigma_r^2 + \sigma_e^2$; on a ainsi $\sigma_r = 0.38$ gauss.

6. Realisation du Groupement des Blocs

Les mesures ont porté sur 276 blocs; la structure particulière des 8 blocs d'extrémités de quadrant interdisait leur passage dans l'hexabloc. A ces 8 blocs, ainsi qu'aux 4 blocs fictifs qui représentent les flux de fuite dans les parties rectilignes du synchrotron, a été affectée arbitrairement la valeur moyenne de l'ensemble des blocs, soit 313.83 gauss. Nous avions alors à étudier la répartition de 288 blocs.

Appliquant la méthode définie plus haut, nous avons cherché à constituer des groupes de 2^{h+1} blocs ayant même induction. En toute rigueur, ce n'est pas possible. Néanmoins, à partir de la suite des blocs rangés selon les inductions croissantes, nous pouvons former une classe avec les 2^{h+1} premiers blocs, une autre avec les 2^{h+1} suivants, etc... et obtenir ainsi $N/2^{h+1}$ classes sensiblement homogènes. L'homogénéité des classes diminue au fur et à mesure que h croît, mais cette imperfection affecte des harmoniques d'ordre de plus en plus élevé, dont l'influence diminue très vite (voir formule 3).

Pour $h = 0$, les classes sont formées de 2 blocs, diamétralement opposés. La disposition des blocs d'une classe par rapport à ceux d'une autre classe est arbitraire. On annule ainsi les harmoniques 1, 3, 5, 7, etc...

Pour $h = 1$, les quatre blocs de chaque classe sont disposés aux sommets d'un carré inscrit dans la circonférence; les classes de la disposition précédente ($h = 0$) sont devenues des sous-classes de cette répartition.

Si 1, 2,... N désignent les 1er, 2ème,... Nème blocs de la suite des inductions croissantes, la figure 8 représente la disposition des blocs pour différentes valeurs de h.

Nous nous arrêtons à $h = 4$ puisque $2^{h+1} = 32$ est la plus grande puissance de 2 qui divise 288; nous avons donc 9 classes de 32 blocs.

Nous disposons la 1ère classe à partir d'une origine arbitraire; la 2ème classe devrait avoir pour origine le milieu de l'arc joignant deux blocs de la 1ère classe, mais ce point n'est pas une position possible pour un bloc; on prend alors, pour origine de la 2ème classe, l'une des deux positions possibles les plus rapprochées du

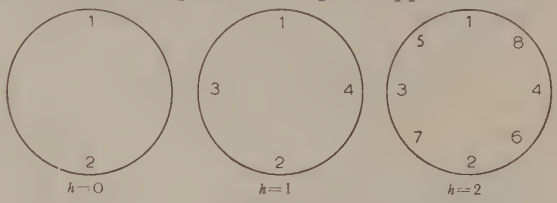

Fig. 8

milieu de l'arc joignant deux blocs de la 1ère classe; on opère de facon analogue pour les classes suivantes.

7. Calcul des Ecarts de l'Orbite Fermé Dus aux Harmoniques

7.1. AVEC UNE RÉPARTITION AU HASARD

Les valeurs réelles de l'induction de chacun des blocs forment une distribution sensiblement gaussienne, d'écart quadratique moyen $\sigma_r = 0.38$ gauss. Supposons que les blocs soient répartis au hasard sur la circonférence. On ne peut calculer de façon certaine l'amplitude d'un harmonique; mais on sait que la probabilité p, pour que l'harmonique b_m soit au plus égal à une certaine valeur B, est (voir[4]):

$$p = 1 - e^{-N\left(\frac{B}{2\sigma_r}\right)^2} . \qquad (7)$$

Cette formule, dans laquelle N désigne le nombre de blocs, est valable tant que m est petit devant N; elle permet de calculer, pour une probabilité donnée (0.95 par exemple), la valeur maximum de chaque harmonique; l'amplitude $X = \sum_m X_m$ des déviations de l'orbite en découle par la formule (4). Nous obtenons le tableau suivant:

p	X_1	X_2	X_3	X_4	X_5	$\sum_m X_m$
0.50	220.8 10^{-3}	30.2 10^{-3}	12.4 10^{-3}	6.8 10^{-3}	4.2 10^{-3}	$300 \cdot 10^{-3}$
0.95	459.6 10^{-3}	62.8 10^{-3}	25.8 10^{-3}	14.0 10^{-3}	9.0 10^{-3}	$620 \cdot 10^{-3}$
0.99	567.6 10^{-3}	77.6 10^{-3}	31.8 10^{-3}	17.4 10^{-3}	11.0 10^{-3}	$760 \cdot 10^{-3}$

Les X sont donnés en centimètres.

[4]) M. H. Blewett, J. M. Kelly et W. H. Moore – Review of Scientific Instruments 24 (1953) 760.

On voit, par exemple, qu'en disposant nos blocs au hasard, nous aurions la probabilité 99% d'avoir une amplitude maximum des déviations de l'orbite inférieure ou égale à 0.76 cm.

7.2. AVEC UNE RÉPARTITION RÉALISÉE COMME IL EST INDIQUÉ PLUS HAUT

En ne tenant pas compte des erreurs de mesure, nous pouvons calculer l'amplitude des différents harmoniques par les formules (2) et (3) et l'amplitude des déviations correspondantes par la formule (4). Nous obtenons le tableau suivant:

X_1	X_2	X_3	X_4	X_5	$\sum_m X_m$
$29.1 \cdot 10^{-3}$	$6.7 \cdot 10^{-3}$	$0.4 \cdot 10^{-3}$	$3.8 \cdot 10^{-3}$	$0.05 \cdot 10^{-3}$	$45 \cdot 10^{-3}$

Les X sont donnés en centimètres.

La suite des amplitudes X_m est rapidement convergente; seuls les harmoniques dont le rang est une puissance de 2 se distinguent par une valeur plus forte, bien qu'elle-même décroissante (on a, par exemple, $X_8 = 0.2 \cdot 10^{-3}$ cm). On obtient, pour amplitude maximum des déviations de l'orbite, 0.045 cm.

Comme nous l'avons dit, ces derniers résultats ne tiennent pas compte des erreurs de mesure. Quand on veut en tenir compte, on doit considérer que la valeur de l'induction B trouvée pour chaque bloc n'est pas la valeur réelle et que l'amplitude des déviations X_m est peut-être supérieure à celle déterminée cidessus.

On peut évaluer approximativement l'effet des erreurs de mesure en calculant les harmoniques dûs à une répartition au hasard de $N = 288$ blocs dont la dispersion est gaussienne et l'écart quadratique moyen égal à celui des erreurs de mesure, soit 0.15 gauss. Le calcul, à partir de la formule (7), donne les résultats suivants:

p	X_1	X_2	X_3	X_4	X_5	$\sum_m X_m$
0.50	$87.2 \cdot 10^{-3}$	$12.0 \cdot 10^{-3}$	$4.8 \cdot 10^{-3}$	$2.6 \cdot 10^{-3}$	$1.6 \cdot 10^{-3}$	$120 \cdot 10^{-3}$
0.95	$181.4 \cdot 10^{-3}$	$24.8 \cdot 10^{-3}$	$10.2 \cdot 10^{-3}$	$5.6 \cdot 10^{-3}$	$3.6 \cdot 10^{-3}$	$240 \cdot 10^{-3}$
0.99	$224.2 \cdot 10^{-3}$	$30.6 \cdot 10^{-3}$	$12.6 \cdot 10^{-3}$	$6.8 \cdot 10^{-3}$	$4.4 \cdot 10^{-3}$	$300 \cdot 10^{-3}$

Les X sont donnés en centimètres.

On voit qu'il y a 99 chances sur 100 pour que l'erreur due à l'imperfection des mesures soit inférieure ou égale à 0.30 cm.

8. Conclusion

Une répartition au hasard aurait donné, avec la probabilité 99%, une amplitude maximum des déviations de l'orbite inférieure ou égale à 0.76 cm.

La répartition, telle que nous l'avons effectuée, donne théoriquement 16 fois moins (0.045 cm). En réalité, l'imprécision de la mesure ne nous permet pas d'affirmer que le gain est d'un facteur 16, mais seulement qu'il est inférieur à ce chiffre.

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A TRANSISTORIZED RADIATION MONITOR †

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This paper describes the investigation of a number of possible semiconductor devices which can be used for the detection of radioactive particles. The sensitivities of two types of transistor (a p-n-p alloy junction and an n-p-n grown junction) and a p-n alloy junction diode operated up to its "avalanche" condition were determined. The possible uses of such detectors are discussed and they are shown to be particularly suitable where high rates of counting, with good efficiency and small detecting area (or low geometry) are required.

A completely transistorized radiation monitor has been developed using a p-n-p transistor as the detector head. This is specifically designed for α-particle detection but the detector head with slight modification should be suitable for proton or neutron detection.

1. Introduction

Crystal particle counters have been described in great profusion in the literature[1,2,3]). Early attempts at detecting particles by means of a crystal detector utilised the effect of electron-hole pair production within a crystal lattice, (often a diamond), by subjecting the crystal to bombardment from some radioactive source. The quantum yield of electron hole pairs is low and a large electric field is required to obtain a sharp current pulse from the system. The same order of field can be produced across a p-n junction and thus a p-n junction can be used as a radioactive particle detector[4,5]).

2. The Types of Detector

By using a transistor in the grounded emitter configuration as the detector (in the same fashion as a phototransistor[6])) the current gain can be utilised to give a greatly increased signal. Current multiplication can also be obtained in the case of a simple p-n junction by using a controlled avalanche effect.

The specific ionisation of the incident radiation determines the magnitude of the current pulse resulting from the arrival of one particle in the sensitive region of the detector. Thus a large signal should result from α-particles, smaller ones from neutrons and protons and very small ones from β and γ-rays. The detectors are all light sensitive but if the light falling on them is steady, such as diffuse daylight, this merely results in the d.c. operating point of the detectors changing and a slight increase in the noise level. Fig. 1 shows the arrangement for obtaining a signal from an n-p-n transistor, a p-n-p transistor and a p-n junction diode which exhibited a controlled avalanche effect. In each case the region within a diffusion length of the p-n barrier is sensitive and for the p-n-p alloy junction transistor either the collector or the emitter side can be bombarded. In the case of the junction diode it is obviously better to bombard from the side opposite to the indium dot as a much greater sensitive area is exposed. Fig. 2 shows a photograph taken of the pulses produced by bombarding an n-p-n grown

† This is part of the work submitted by B. P. Faraday for the Diploma of the College of Aeronautics in the Department of Aircraft Electrical Engineering.

[1]) R. Hofstadter, Crystal counters, Part. 1, Nucleonics (April 1949) 2.

[2]) R. Hofstadter, Crystal counters, Part. 2, Nucleonics (May 1949) 29.

[3]) H. Ess and J. Rossel, Some properties of diamond as a crystal counter, Helv. Phys. Acta (September 1950) 484.

[4]) K. G. MacKay, A germanium counter, Phys. Rev. (November 1949) 1537.

[5]) C. Orman *et al.*, Germanium p-n barriers as counters, Phys. Rev. (June 1950) 646.

[6]) J. N. Shive, The properties of germanium phototransistors, J. Opt. Soc. America (April 1953) 239.

junction transistor with 5 MeV α-particles from a polonium 210 source. The pulses produced are of the order of 10μ seconds wide, most of the pulse broadening being due to the shunt capacitance of the transistor itself (about $40\mu\mu$F). The recovery time of the detector is such that pulses separated by 20μ seconds are clearly resolved.

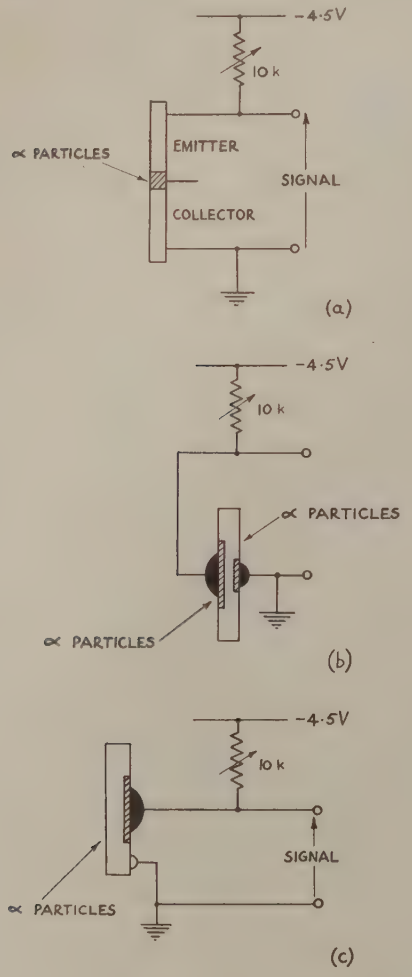

Fig. 1. The method of using (a) an n-p-n junction transistor and (b) a p-n-p alloy junction transistor and (c) a p-n alloy junction diode as detectors of α-particles.

If the collector current of the detector is increased the sensitivity increases rapidly at first and then becomes almost constant in much the same way as a phototransistor. The graphs

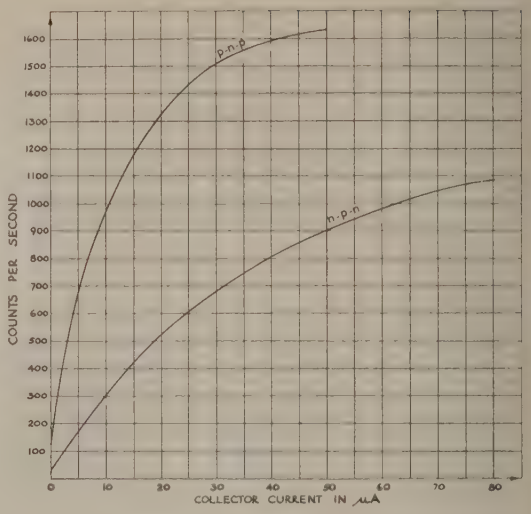

Fig. 3. The variation of counting rate of a p-n-p alloy junction transistor and an n-p-n grown junction transistor as the collector current is varied.

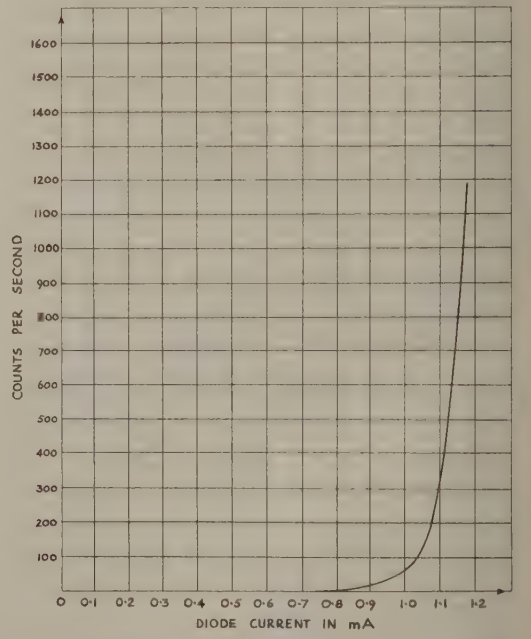

Fig. 4. The variation of counting rate of a p-n junction diode (which exhibited an avalanche effect) with increase in the reverse current.

shown in fig. 3 illustrate this effect by recording the number of pulses which occur when an α-source is placed a fixed distance from the

detector and the bias current is varied, the clipping level being set so that there was negligible contribution to the count by noise pulses. For the avalanche diode when the reverse current is increased the sensitivity increases very rapidly until a critical stage is reached when an uncontrolled avalanche occurs. The sensitivity curve for an avalanche diode is shown in fig. 4. The p-n-p transistor seems superior to the n-p-n transistor because although its current gain is inherently less than that of the n-p-n transistor the optimum working point is reached at a very much lower bias current. This means that for the same bias voltage supply the signal developed across the resistor in the collector is greater for the p-n-p transistor than for the n-p-n transistor. The avalanche diode is rather an unreliable detector as a small change in bias current results in a large change in sensitivity and if the initial bias condition is near the critical current it is possible for the device to become unstable. If the sensitive area of the detectors is measured experimentally then their efficiency can be determined by placing them at a known distance from a sub-standard α-source in a collimating chamber which can be evacuated[7]). Efficiencies, (that is the ratio number of counts recorded to the theoretical number of counts which should occur knowing the d.p.m. of the source and the geometry of the system) up to 0.5 were recorded, depending on the state of the surface contamination.

3. The Possible Uses of Semiconductor Radiation Detectors

Such a detector can be of great use where a low geometry counter is required of good efficiency at high rates of counting. Thus it could be used in a probe head for accurately locating metallic plutonium in one of the plutonium alloys. It should also be possible for high energy protons to be detected directly and thus the detector could be used to determine accurately the profile of proton and other beams

[7]) R. Hurst and G. R. Hill, A low geometry proportional counter for α counting, A.E.R.E. C/R 647.

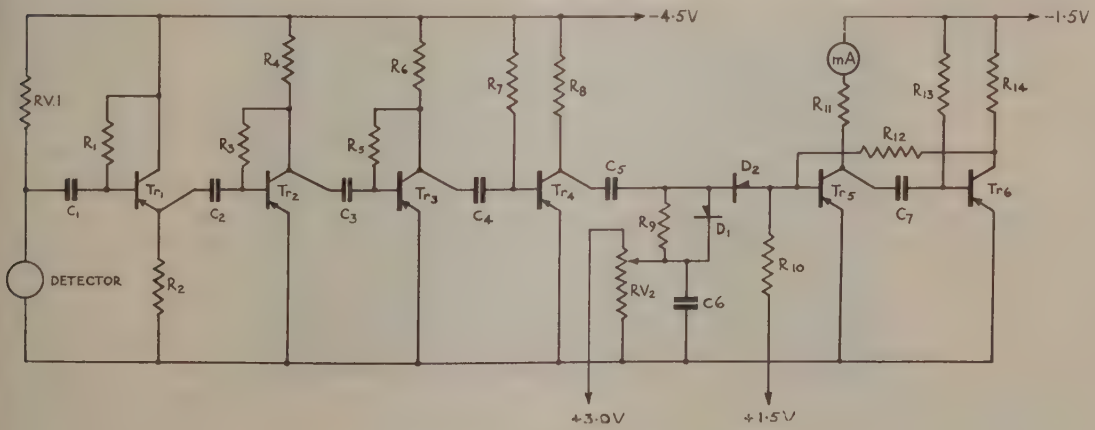

Fig. 5. The circuit diagram of the detector.

$RV_1 = RV_2 = 10\text{k}\Omega$
$R_1 = R_3 = R_5 = R_{10} = 220\text{k}\Omega$
$R_2 = R_4 = R_6 = R_8 = 5.6\text{k}\Omega$
$R_7 = 270\text{k}\Omega$
$R_9 = 100\text{k}\Omega$
$R_{14} = R_{11} = 2.2\text{k}\Omega$
$R_{12} = 10\text{k}\Omega$
$R_{13} = 22\text{k}\Omega$

$C_1 = C_2 = C_3 = C_4 = C_6 = 0.04\mu\text{F}$
$C_5 = 0.001\mu\text{F}$
$C_7 = 0.07$ or $0.007\mu\text{F}$

$D_1 = D_2 =$ G.E. 10
$Tr_1 = Tr_2 = Tr_3 = Tr_4 =$ S.T.C. Type TS 3
$Tr_5 = Tr_6 =$ S.T.C. Type TS 2

from accelerators. It could also be used for detecting thermal neutrons by placing a boron screen between the detector and the source†, or fast neutrons by using a paraffin moderator before the boron screen.

4. The Radiation Monitor

An instrument has been designed incorporating a transistor detector which is primarily intended for α-particle detection but which, with minor adjustments, could be used for other types of radiation. The instrument is intended to be a portable monitor and is completely transistorized, the circuit diagram being shown in fig. 5.

A high input impedance is required from the detector to the amplifier and if it is to be used on a probe some distance from the amplifier a low output impedance is desirable. A grounded collector transistor or a grounded emitter transistor with degeneration introduced by having an undecoupled emitter resistor will produce the necessary high impedance, the output impedance from a grounded collector stage however is much lower than that from a grounded emitter stage.

Using the h parameters the input impedance of the grounded collector stage is given by

$$Z_{\text{in}}'' = \frac{1 + h_{11}y_{\text{L}}}{h_{22} + y_{\text{L}}(1 + h_{21})} \qquad (1)$$

(y_{L} being the collector load conductance) and of the grounded emitter stage with an emitter resistor R_{E} by

$$Z_{\text{in}}' = \frac{(h_{11} + R_{\text{E}})(h_{22} + y_{\text{L}}) - h_{12}h_{21}}{h_{22} + y_{\text{L}}(1 + h_{21})} . \qquad (2)$$

This must be large with respect to the output impedance of the detector which is approximately equal to RV_1 and should be at least 50kΩ. Using a transistor with a value of h_{21} approaching —1 this can be easily attained for both configurations. Assuming values of h parameters as follows

h_{22} 1.0 μmho
h_{21} —0.98
h_{11} 40 ohms
h_{12} 4×10^{-4}

$Z_{\text{in}}' = 50\text{k}\Omega$ results from $y_{\text{L}} = 10^{-3}$ mho and $R_{\text{E}} = 1\text{k}\Omega$

The output impedance of a grounded collector stage is given by

$$Z_0'' = \frac{h_{11} + Z_{\text{g}}(1 + h_{21})}{1 + Z_{\text{g}}h_{22}} \qquad (3)$$

and for a grounded emitter stage with an emitter resistor R_{E}

$$Z_0' = \frac{(h_{11} + R_{\text{E}}) + Z_{\text{g}}(1 + h_{21})}{(h_{11} + R_{\text{E}})h_{22} - h_{21}h_{12} + h_{22}Z_{\text{g}}} . \qquad (4)$$

If the generator impedance Z_{g} is taken to be equal to RV_1, 10kΩ say, and R_{E} taken as 1kΩ for the grounded emitter configuration and the h-parameters as before then

$$Z_0'' = 240\Omega$$
$$Z_0' = 120\text{k}\Omega .$$

It is preferable to use a grounded collector stage configuration for the input stage from the detector and the theoretical input and output impedances for the actual circuit shown are

$$Z_{\text{in}}'' = 150\text{k}\Omega$$
$$Z_0'' = 240\Omega$$

taking into consideration the increase of y_{L} because of the presence of the main amplifier.

Transistors Tr_2, Tr_3 and Tr_4 constitute a conventional amplifier having a bandwidth of about 50 kc/s. The output from this amplifier is in the form of negative pulses superimposed on a background of noise. In order that the gain of the amplifier can be usefully employed at high counting rates the signal is clamped to a variable positive level by means of the germanium diode D_1 and the signal injected into the monostable multivibrator Tr_5 and Tr_6 by means of another germanium diode D_2 so that only signals more negative than the base potential of Tr_5 can be applied to the multivibrator. The base of Tr_5 is arranged to be at earth potential in its stable state, so that by varying the potentiometer RV_2 the signal can be clipped at any level from zero to three volts.

The multivibrator is a conventional one[8]) with Tr_6 conducting in the stable state. Capacitor

† $5\text{B}^{10} + 0\text{n}^1 \rightarrow 3\text{Li}^7 + 2\text{He}^4$ the α-particles having an energy of 2.78 MeV.

[8]) J. E. Flood, Junction transistor trigger circuits, Wireless Eng. (May 1955) 122.

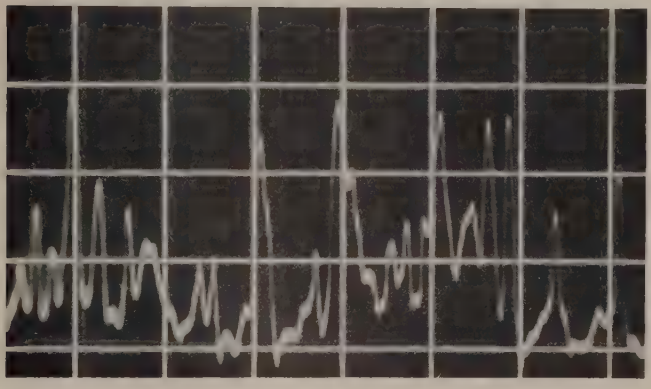

Fig. 2. The output from an n-p-n grown junction transistor when the collector is bombarded with 5 MeV α-particles. The time scale is such that one square represents 100μ seconds.

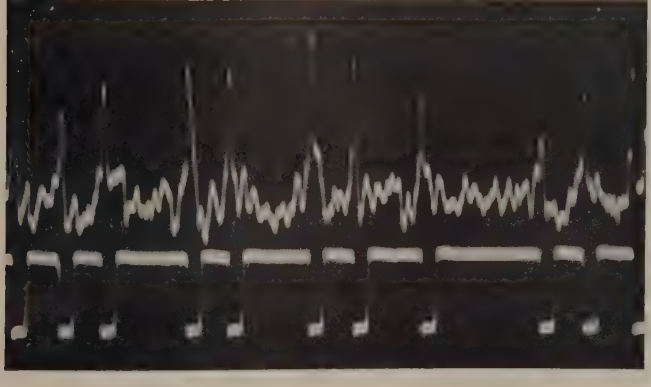

Fig. 7. The output of the amplifier when the detector is bombarded with 5 MeV α-particles together with the output of the monostable multivibrator.

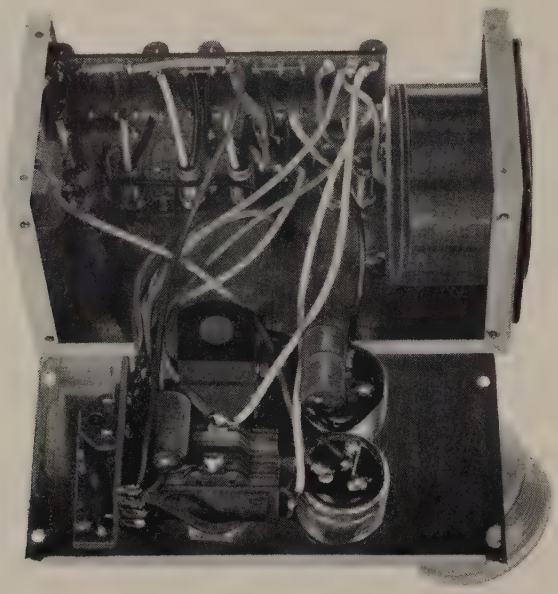

Fig. 8. The monitor showing the indicator meter, control panel and detector with the cover removed.

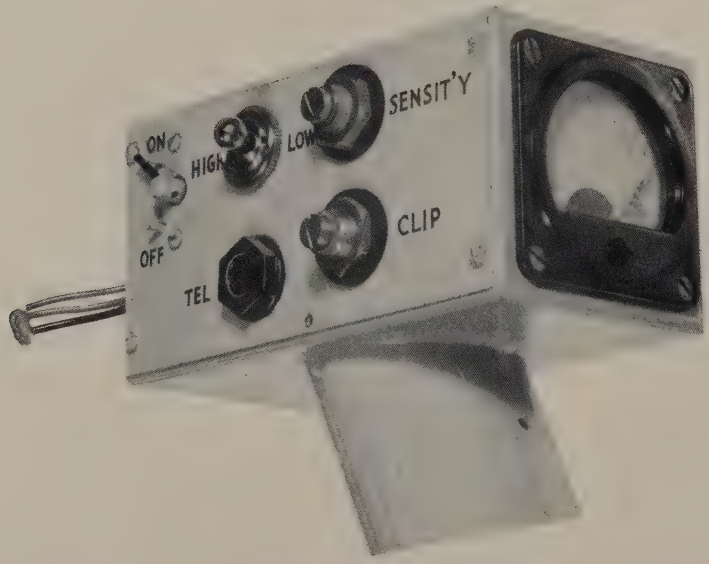

Fig. 9. A view of the interior of the monitor showing constructional details.

C_7 can be switched from 0.007 μF to 0.07 μF giving a change in pulse width of almost ten to one. By placing a 250 μA meter in the collector lead of Tr_5, the current flowing at any time through the meter is directly proportional to the number of times the multivibrator is triggered and the width of the pulse produced by the multivibrator. This system behaved in a very efficient manner as an integrator, fig. 6 showing how the meter current varies when the frequency of the incoming pulses is varied at both high and low rates of counting. The linearity is not as good as this for random pulses at a high rate, because too many pulses occur during the recovery time of the multivibrator, or at a very low rate, because of the finite inertia of the meter movement. Fig. 7 shows a typical set of random pulses applied to the multivibrator and the resultant multivibrator output.

The complete monitor is shown in fig. 8 and in fig. 9 the side panel is removed to show some of the constructional details. The instrument is completely self-contained, including the battery supplies which are in the handle. When the detector is used for α-particle detection it can be protected from surface contamination by means of a very thin coating of silicone grease which only reduces the efficiency slightly.

The authors are grateful to the staff of the Department of Aircraft Electrical Engineering, the College of Aeronautics, for their co-operation and the interest shown during the development of this instrument. In particular they would like to thank Mr. E. C. Sills, the head of the Instrumentation Section, who not only built the portable monitor shown in fig. 8, but contributed a considerable amount to the design of the integrator circuit.

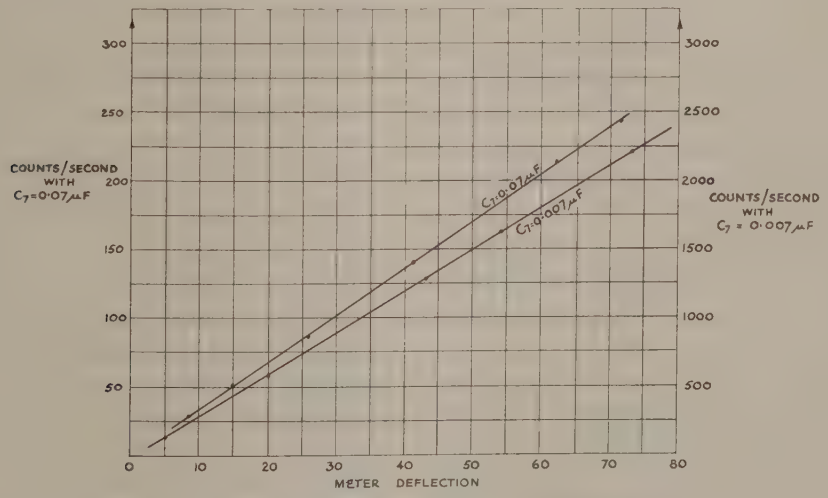

Fig. 6. The calibration of the integrator for two different ranges.

NUCLEAR INSTRUMENTS 1 (1957) 138–142; NORTH-HOLLAND PUBLISHING CO. – AMSTERDAM

THE LOADING OF NUCLEAR EMULSIONS WITH WATER

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Department of Physics, University of Birmingham

Received 9 January 1957

The rate of absorption of water by G5 emulsions has been studied at temperatures between 6° and 18° C, and the relation between swelling and water content determined. The volume of the swollen emulsion is generally less than the sum of the volumes of water and dry emulsion, and this can affect cross-section measurements. The grain density of 540 MeV proton tracks falls by about a third when 3 g of water is absorbed in 1 cm^3 of dry emulsion. An area scan for p-p elastic collisions gives, as expected, a reduced ratio of background events in the loaded emulsion.

1. Introduction

Much use has been made of the technique, initiated by Goldhaber[1]), of using the hydrogen nuclei normally present in nuclear research emulsions for proton-proton and meson-proton scattering experiments. However, the low hydrogen content, of the order of 0.05 $g \cdot cm^{-3}$, makes scanning long and tedious and limits the number of events which may be found if the experiment is not to take an excessive amount of time. Goldhaber[2]) loaded emulsions with heavy water and later[3]) showed that plates loaded with water or heavy water retained the property of detecting minimum ionization particles.

2. Procedure

Ilford G5 and C2 emulsions up to 400 μ in thickness were soaked in distilled water at room temperature, removed after reaching the correct water loading as determined below, lightly blotted to remove excess moisture, placed in a light-tight container and exposed to the beam of particles to be studied. After exposure the plates were developed either by the temperature development procedure[4]) or if 200 μ or less in thickness by a "dish development" procedure which does not use any "cold stage" but allows the development to take place at room temperature. The plates were washed and fixed as usual. If the plates could not be developed immediately after exposure it was found advisable to return them to a bath of distilled water until development could take place; if they were allowed to dry and then developed, a dense black film formed on the surface of the emulsion.

In order to measure the quantity of water which the emulsion absorbed during the soaking procedure it was found convenient to measure the swelling of the emulsion which occured as it absorbed water. The ratio of the thickness of the emulsion when loaded to its thickness when dry is defined as the "swelling-factor" of the emulsion and provided a convenient measure of the amount of water absorbed and hence of the hydrogen content of the emulsion. The "loading" of an emulsion is defined as the mass of water absorbed in grams by one cm^3 of the dry emulsion.

The combined thickness of the emulsion and glass was measured when dry, when loaded with water and finally after development. These measurements were made using a Mercer dial micrometer which can easily be read to 1 μ.

The thickness of the developed emulsion was also measured using the fine focus scale of a Cooke M 4000 microscope and hence the thickness

[1]) G. Goldhaber, Phys. Rev. **87** (1952) 220.
[2]) G. Goldhaber, Phys. Rev. **74** (1948) 1725.
[3]) G. Goldhaber and S. Goldhaber, Phys. Rev. **87** (1952) 185.
[4]) A. D. Dainton, A. R. Gattiker and W. O. Lock, Phil. Mag. **42** (1951) 396.

of the glass found. In this way the swelling factor and shrinkage factor[5]) were determined.

3. Properties

Experiments were first carried out to investigate the rate at which emulsions of various

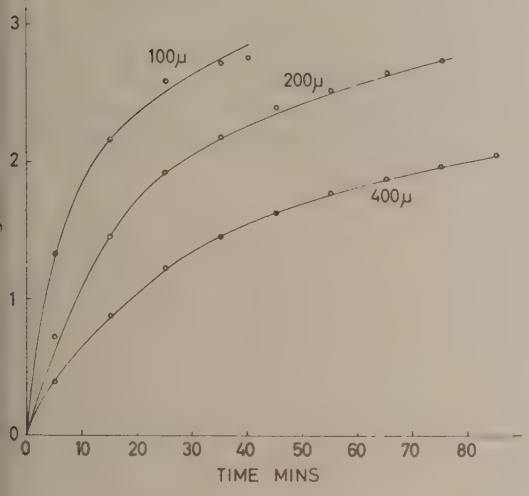

Fig. 1. Mass of water absorbed per cm^3 as a function of time for G5 emulsions of various thicknesses.

as a function of water loading it can be deduced that for the particular batch in question 1 g of

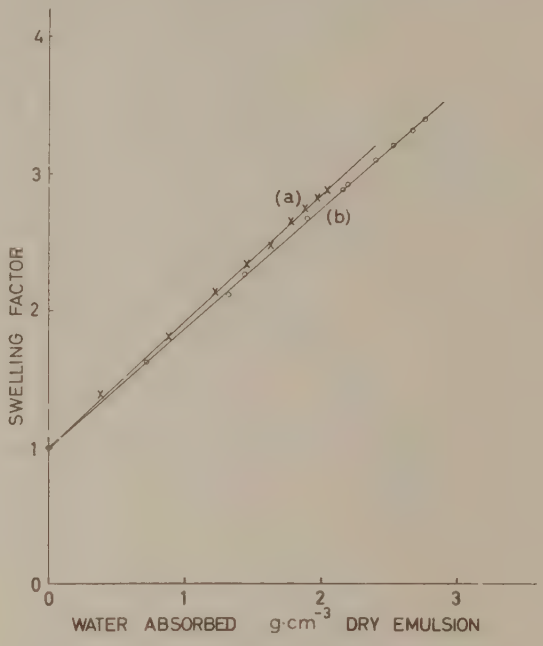

Fig. 2. Variation of swelling factor with amount of water absorbed for (a) 400 μ C2 and (b) 200 μ G5 emulsions.

thicknesses absorb water and also how the swelling factor varies with amount of water absorbed. The mass of water absorbed was measured by weighing the emulsion and glass dry, and then after various periods of soaking in distilled water. The emulsion was then finally stripped off the glass which was weighed in order to determine the true weight of emulsion. The swelling factor was measured as shown before except that in this case the thickness of of the glass was measured directly.

The mass of water absorbed cm^{-3} of dry emulsion as a function of time is shown in fig. 1. The variation of swelling factor with amount of water absorbed is shown in fig. 2. These results have been found to be consistent for plates from one batch, but vary appreciably for different batches.

From the slope of the graph of swelling factor water occupies 0.875 ± 0.02 cm^3 when absorbed in G5 emulsions and 0.93 ± 0.02 cm^3 in C2 emulsions. For different batches of G5 emulsion this figure has been found to vary between 0.84 and 1.00. Waller[6]) obtained the value 0.837 $cm^3 \cdot g^{-1}$ of water absorbed in G5 emulsions for small changes in water content due to changes in atmospheric humidity. At infinite dilution the figure must clearly be 1.0 $cm^3 \cdot g^{-1}$. It is therefore not surprising that our figure should lie between the two.

This contraction of the water into a smaller volume is an important effect in cross-section measurements. If the water content is determined only by weight and a 1:1 relationship is assumed, the calculated number of atoms of

[5]) P. J. Duke, W. O. Lock, P. V. March and B. A. Munir, J. Sci. Inst. **32** (1955) 365.

[6]) C. Waller, Private Communication (1955).

hydrogen cm^{-3} may be in error by about 10%. This will be reflected in the cross-section results if the scanning is along the track, or if the flux

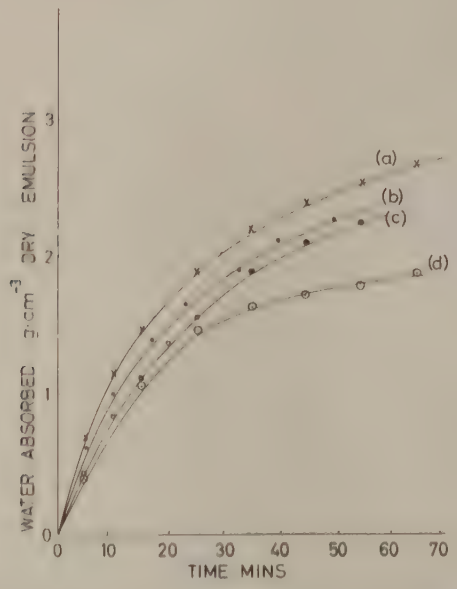

Fig. 3. Variation of rate of absorption with temperature for 200 μ G5 emulsions (a) 18° C (b) 13° C (c) 8° C (d) 6° C.

density is determined by counting tracks in the plates. If however the flux is determined by measurements external to the emulsion, as in the case of neutral particles, no error results, since in this case it is not the hydrogen density but only the total number of hydrogen atoms per unit area of the plate which is important. It is probable that a similar effect also occurs for heavy water. The analysis of events will of course also be affected, as the dip angles will be incorrect.

Since the volume occupied by 1 g of water in different batches of emulsion seems to vary, for accurate work it would be necessary to measure this parameter for every batch.

The temperature dependence of the rate of absorption of water for one batch of emulsions was next investigated for 200 μ G5 emulsions with the results shown in fig. 3. The curves for different temperatures are of a similar shape but the amount of water absorbed approaches a smaller value at lower temperatures.

The swelling factor, however, was found to be independent of temperature within the range measured (3° to 18°C). Hence we are able conveniently to use the swelling factor as a measure of the amount of water absorbed.

Assuming the value 0.875 cm^3 for the volume occupied by 1 g of water in emulsion, and the composition of the emulsion, it is possible to calculate the hydrogen content in $g \cdot cm^{-3}$ of swollen emulsion, and also the ratio of hydrogen

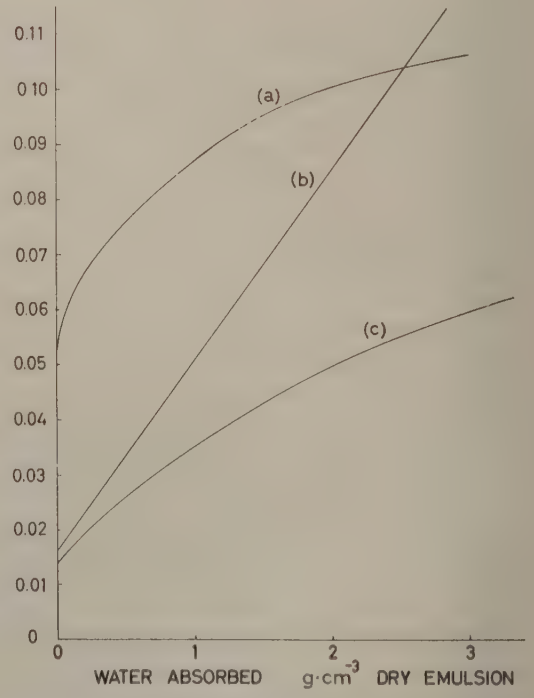

Fig. 4. Properties of water loaded G5 emulsions as a function of amount of water absorbed. (a) Hydrogen content in $g \cdot cm^{-3}$ of wet emulsion (b) Ratio of hydrogen content to silver and bromine content. (c) Ratio of hydrogen content to all other elements

content to either silver and bromine or to all other elements present, as a function of the quantity of water absorbed. The results for G5 emulsions are plotted in fig. 4.

The possibility of any soluble substances in the emulsion being removed by the soaking in water and hence invalidating the previous measurements has been investigated. It has been found that about 1% by weight of the emulsion is removed by soaking the plate in water and then allowing it to dry again. This is probably due to the glycerine used as a plasticiser and should have a negligible effect on the measurements.

To measure the variation of sensitivity of the emulsion with loading by water, the grain densities of 540 MeV proton tracks from the Birmingham proton-synchrotron have been

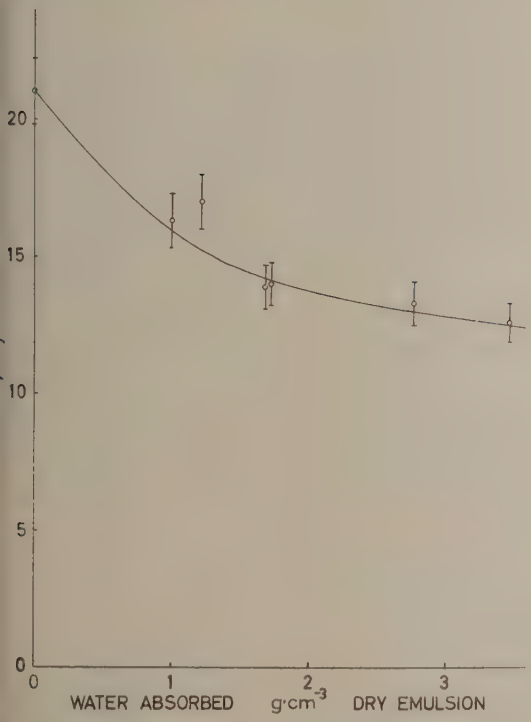

Fig. 5. Variation in grain density with loading for G5 emulsions.

measured in loaded and normal G5 emulsions. The emulsions were all exposed and developed together in order to minimise any variation of grain density due to other causes. The plates were developed for the normal time for G5 emulsions. The results are shown in fig. 5 where it is seen that the grain density falls slowly with increase in amount of water absorbed. This decrease in grain density is a small effect and should not cause any difficulty in either the scanning for, or measurement of, events found in loaded emulsions.

4. Ratio of Hydrogen to Heavy Elements

It is a feature of water loaded plates that the ratio of hydrogen content to silver and bromine content is much increased by the loading, as shown in figure 4. This can simplify the analysis of particular events where the background of unwanted events is mainly due to reactions taking place in heavy elements. This is particularly true in the case of proton-proton elastic scattering (p-p) where nearly all two-prong stars which are not true p-p events originate in heavy elements. This has been shown by the work of Philbert[7]) who found the following cross-sections for the production of two-prong stars in light and heavy elements at 950 MeV.

$$\sigma_{C,N,O} = 11\,^{+20}_{-19}\ \text{mb}$$

$$\sigma_{Ag,Br} = 260\,^{+19}_{-20}\ \text{mb}.$$

In order to test this feature of loaded emulsions, a 400 μ G5 plate loaded to 0.93 g·cm^{-3} was exposed to a 540 MeV proton beam from the Birmingham Synchrotron at an average intensity of 9×10^4 protons cm^{-2}. 4.2 cm^2 were then area scanned for two pronged stars. Thirty events were found which were analysed by the method of Duke *et al.*[8]) to discover any proton-proton elastic scatterings. Four events had ϕ less than 1°30′ and $\Delta\alpha$ less than 2°30′ and hence can be classified as probable proton-proton elastic scatterings. The remaining events had either values of ϕ and $\Delta\alpha$ widely outside these limits or could be rejected by inspection.

The four events found represent an average of 6.5 ± 4.5 background events per p-p at 540 MeV within the very limited statistics, whilst Duke *et al.*[8]) in the along-track scanning

[7]) G. Philbert, Comptes Rendus Acad. Sci. **243** (1956) 141.

[8]) P. J. Duke, W. O. Lock, P. V. March, W. M. Gibson, R. McKeague, I. S. Hughes and H. Muirhead, Phil. Mag **46** (1955) 877; Phil. Mag. (In the Press) and Private Communication.

of 950 MeV protons obtain 16.1 ± 4.7 background events per true p-p or 11.9 ± 4.7 if the elastic events are corrected for azimuthal loss.

The results of Philbert[7]) would predict 9.3 ± 1.3 background events per p-p for unloaded emulsions and 3.3 ± 0.5 events for an emulsion loaded as above, at 950 MeV. These figures are in agreement with the experimental values.

My thanks are due to Dr. S. J. Goldsack for his help and advice; to Mr. P. J. Duke for many valuable discussions and to Mr. D. Hoare for assistance with some of the measurements. I especially wish to thank Dr. G. Goldhaber of the University of California, Berkeley, U.S.A. for his helpful criticism.

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SCINTILLATION SPECTROMETER WITH CONSTANT RELATIVE CHANNEL WIDTH

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Nobel Institute of Physics, Stockholm 50

Received 10 January 1957

It is shown that many of the difficulties involved in making automatic recordings of the γ-spectra measured with a scintillation spectrometer can be eliminated by using a pulse amplitude discriminator with a varying channel width. The circuit of such a discriminator is given. It is also shown how γ-intensity ratios can be evaluated from different types of measurements.

1. Introduction

The scintillation spectrometer has proved to be a very useful instrument for many types of routine measurements in a laboratory working with radioactive materials. With an increasing number of measurements it is desirable to make the instrument work automatically and present the data directly in the form of a spectrum drawn by a recorder.

This paper describes how a single channel pulse-height analyzer was modified to make it more useful in a set-up of this type.

A typical spectrum of the γ- and X-rays of Cs^{137} measured with a conventional scintillation spectrometer using a $1\frac{1}{2}'' \times 1''$ NaI (Tl) crystal is shown in fig. 1. The single-channel amplitude discriminator used had a channel width of 1 volt. By an automatic arrangement this channel scanned the amplitude range 0–100 volts in one volt steps. The output pulses of the discriminator were counted by a counting rate meter and the spectrum thus obtained was recorded by a potentiometer recorder.

The fact that in this type of spectrometer the relative channel width is inversly proportional to the pulse amplitude, gives the spectrum a less satisfactory shape, especially for automatic recording. Low energy peaks appear with very high counting rates and the heights of these peaks determine the sensitivity of the recorder

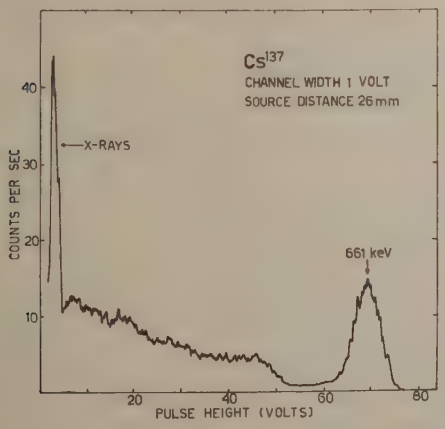

Fig. 1. Automatically recorded scintillation spectrum of Cs^{137} using a $1\frac{1}{2}'' \times 1''$ NaI(Tl) crystal and an ordinary single-channel pulse-height discriminator.

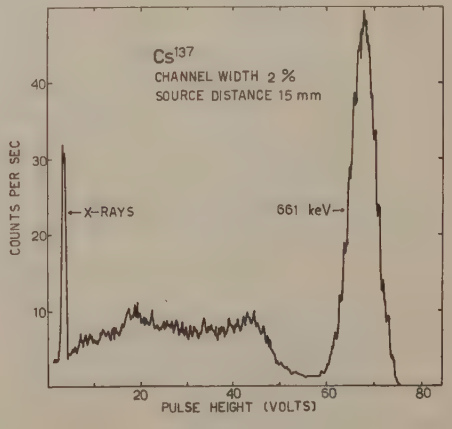

Fig. 2. The same Cs^{137} spectrum recorded with a constant relative channel width.

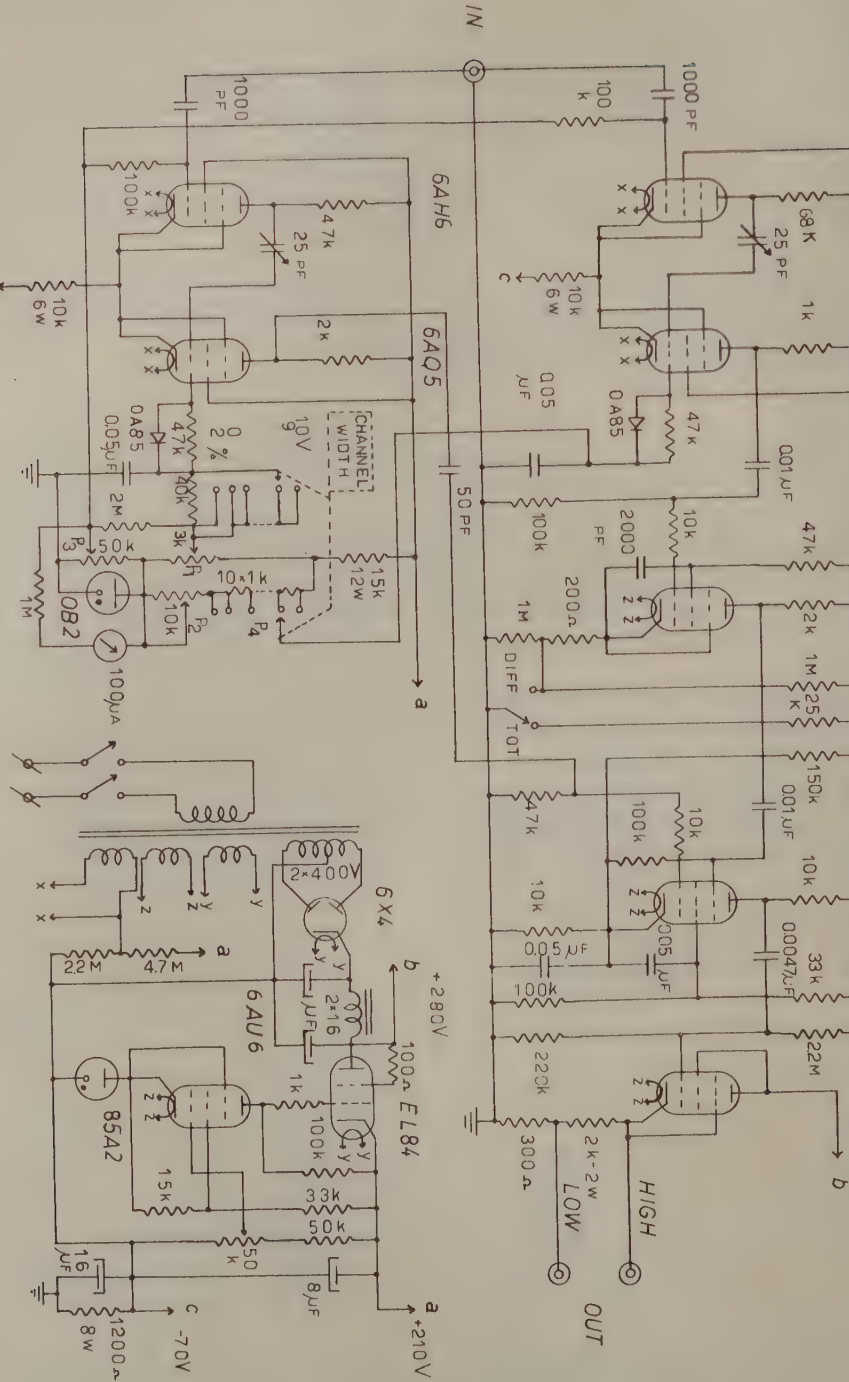

Fig. 3. Circuit of the single-channel pulse-height discriminator.

that can be used if one wants to keep these peaks within the range of the recorder. High energy peaks will then look very small and peaks in the intermediate energy region must be read from a sloping background. The situation is even more accentuated by the decreasing efficiency of the crystal at higher energies. Some of these difficulties can be eliminated by using a logaritmic counting-rate meter, but such an instrument is rather complicated and not so commonly available.

2. Spectrometer with Constant Relative Channel Width

A more satisfactory result was obtained by making the channel width proportional to the pulse amplitude i.e. making the relative channel width constant.

To accomplish this, a single-channel discriminator described earlier[1]) has been slightly changed. The new circuit is given in fig. 3.

Potentiometers P_1 and P_2 are adjusted to set zero on the energy scale and channel width respectively. P_3 is the bias potentiometer and 2% of the bias voltage is used to shift the

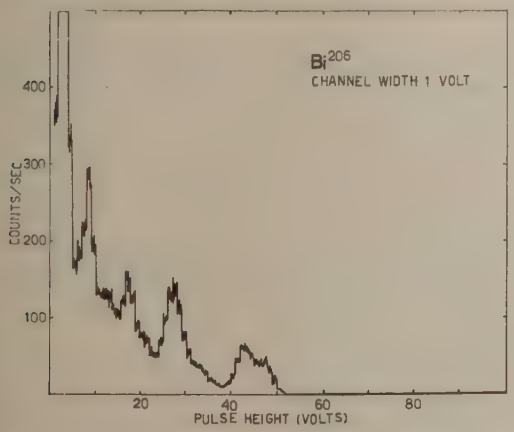

Fig. 4. Spectrum of Bi^{206}, recorded with constant channel width. Energy calibration is the same as in fig. 5.

triggering level of the lower discriminator when the channel width switch is in the 2% position.

When automatic runs are made a stepping relay voltage divider controlled by an electronic timer is connected instead of the 10-turn helipotentiometer P_3.

In fig. 2 is shown the Cs^{137}-spectrum run with a 2% channel width. Other experimental conditions were exactly the same as when the spectrum of fig. 1 was recorded, except that the source to crystal distance could be decreased from 26 mm to 15 mm without either of the two peaks extending out of the range of the recorder.

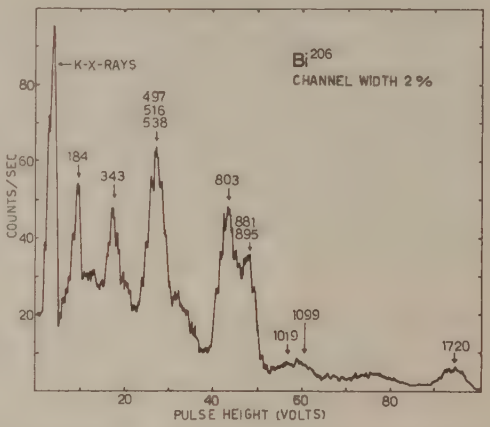

Fig. 5. Spectrum of Bi^{206}, recorded with constant relative channel width. Gamma energies indicated are taken from Alburger[2]).

To demonstrate the advantages of the new spectrometer for automatic recording of complicated spectra, the runs of fig. 4 and 5 were made. The same geometry was used in both cases and the sensitivity of the counting-rate meter was adjusted to give the 184 keV peak the same height. With a constant channel width, it was not possible to record any γ's with an energy higher than 900 keV and the X-ray peak is too high to be measured. In the other run, fig. 5, with constant relative channel width, the height and energy of all principal peaks, including the X-ray peak, can be measured.

3. Measurements Made with the Spectrometer

It has already been pointed out that this new discriminator has made it possible to record automatically γ-spectra involving both high and

[1]) B. Åström, Ark. f. Fysik 7 (1953) 241.

[2]) D. E. Alburger and M. H. L. Pryce, Phys. Rev. 95 (1954) 95.

low energy peaks without the use of complicated switching arrangements for the counting-rate meter. As will be described elsewhere, the spectrometer has been used mainly to analyze mixed samples produced in cyclotron and pile irradiations and electromagnetic isotope separations. This was done by measuring the energy and following the decay of the different peaks in the spectra. The height of a certain peak is proportional to the number of quanta of the corresponding energy being absorbed in the crystal. The decay curve can thus be constructed by making successive runs and plotting the peak height versus time.

4. Comparison of Intensities Using Peak Areas

For a more general comparison of intensities, the following expressions have been derived.

$$\frac{N_1}{N_2} = \frac{\Delta V_2}{\Delta V_1} \cdot \frac{A_1}{A_2} \tag{1}$$

where N = number of quanta, belonging to a certain photopeak
ΔV = absolute channel width
A = measured area of photopeak.

For a *constant channel width* (ΔV = const.), eq. (1) becomes

$$\frac{N_1}{N_2} = \frac{A_1}{A_2} \tag{2}$$

which means that intensity ratios are directly given by the ratio of the peak areas. The position of the peak on the discriminator scale does not enter into this equation, which shows that the area of the peaks to be compared can be measured at the same position on the discriminator scale by shifting the gain of the amplifier. This eliminates errors that could be introduced if ΔV is not quite constant over the whole discriminator range.

For a *constant relative channel width* ($\Delta V/V$ = const.) one has

$$\Delta V = p \cdot V$$

where p = relative channel width
V = peak position on discriminator scale.

Eq. (1) than becomes

$$\frac{N_1}{N_2} = \frac{V_2}{V_1} \cdot \frac{A_1}{A_2}. \tag{3}$$

In this case the ratio of the peak areas gives the intensity ratio only when the peaks are measured in the same position. In all other cases, for instance when the areas are taken from a complete spectrum, the position of the peaks must be taken into account.

5. Comparison of Intensities Using Peak Heights

If one wants to compare intensities by peak heights, the following basic equation holds:

$$\frac{N_1}{N_2} = \frac{\Delta V_2}{\Delta V_1} \cdot \frac{h_1}{h_2} \cdot \frac{V_1}{V_2} \cdot \sqrt{\frac{E_2}{E_1}} \tag{4}$$

where h = measured height of peak
E = gamma energy.

In deriving this equation, it has been assumed that the relative width of a photopeak varies inversely with the square root of the gamma energy.

When using a *constant channel width* (ΔV = const.) (4) becomes

$$\frac{N_1}{N_2} = \frac{h_1}{h_2} \cdot \frac{V_1}{V_2} \cdot \sqrt{\frac{E_2}{E_1}} \tag{5}$$

or, if the peak heights are measured from a complete spectrum, that is, without change of amplifier gain

$$\frac{N_1}{N_2} = \frac{h_1}{h_2} \cdot \sqrt{\frac{V_1}{V_2}}. \tag{6}$$

This equation shows why, in ordinary spectrometers, the low energy peaks become dominant.

With a *constant relative channel width* ($\Delta V/V$ = const.) eq. (4) can be written

$$\frac{N_1}{N_2} = \frac{h_1}{h_2} \cdot \sqrt{\frac{E_2}{E_1}}. \tag{7}$$

In this case one can see that the peak height is independent of the peak position on the discriminator scale. The energy dependance is such that the low energy peaks, which are often more intense, are reduced in height.

To summarize, one can say that for the most exact intensity comparisons, eq. (2) should be

used. The other equations are based on assumptions as to the linearity of the discriminator scale and constancy of the channel width which are never quite fulfilled in practice. From automatic runs using a constant relative channel width approximate intensity comparisons can be made according to eq. (7). However, the intensity ratios so obtained should be considered as only estimates, especially if the energy differences involved are large.

All intensity ratios calculated from the above equations should, of course, be corrected for the absorption efficiency of the crystal at different energies.

The author whishes to thank Professor Manne Siegbahn and Prof. Kai Siegbahn for the continuous interest in this work, and Mr. B. Johansson, Mr. B. Carlsson and Mr. R. Åkerlund for skilled technical assistance. The work has been supported by the Swedish Atomic Energy Commission.

NUCLEAR INSTRUMENTS 1 (1957) 148–151; NORTH-HOLLAND PUBLISHING CO. – AMSTERDAM

ELIMINATION OF END EFFECTS IN PROPORTIONAL COUNTERS

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Received 25 February 1957

The method of Rossi and Staub (ref. [2]) for eliminating end effects in proportional counters has been extended to much smaller wire thicknesses, thus making it suitable for most practical applications. The technique developed for the wire construction is described in detail.

1. Introduction

For many applications in nuclear physics investigations the sensitive volume of proportional counters should be accurately defined and the gas amplification factor should be constant throughout this volume. The sensitive part of the wire therefore has to be strictly limited at both ends, without distortion of the electric field (end effect). At one end this can be achieved most simply by an insulating bead in the wire. At the other end, at which the electrical connection is attached, the wire has to be screened by a concentric electrode, which is kept at a potential corresponding to its radius in the undisturbed electric field. The diameter of this electrode may be either considerably larger than that of the wire (Cockroft and Curran[1])) or equal to it (Rossi and Staub[2])). From the point of view of counter construction the two methods are entirely different. In Cockroft and Curran's method, the screening electrode or field tube is mounted as a separate electrode within the counter and an appropriate tension has to be supplied to it from the outside. In Rossi and Staub's method, the screening electrode forms mechanically part of the wire system and has the same potential as the wire. In contrast with the method of Cockroft and Curran, this method has found little application so far, due to the difficulty of construction of the wire system for wire thicknesses normally used in proportional counters (about 0.1 mm). Rossi and Staub used hypodermic needles with a diameter of 1 mm.

We have developed a technique for preparing wires with a diameter as low as 0.1 mm for the above purpose. This technique will be described in the next section. Although the application requires some equipment and experience, it offers the advantage that, the wire once being prepared, the counter construction is much simpler than in the case of Cockroft and Curran's method.

2. Counter wire construction

The screened part of the wire consists of a platinum core with a thickness of about half the counter wire diameter, which is covered with glass, the total thickness being nearly equal to that of the sensitive part of the wire. On the glass surface a gold layer is evaporated, which serves as the screening electrode. The technique, used by us to construct such a wire will be described in some detail in this section.

Fig. 1 gives a schematic view of the apparatus used for covering thin platinum wires with glass. The Pt-wire is drawn through a molten droplet of soft glass at a uniform speed. The glass sticks to the wire and forms a uniform layer around it.

The glass is molten in a miniature oven, a section of which is shown separately in fig. 1. Two strips of thin platinum sheet are cut out as shown (a) and pressed between two porcelain pieces (b) which have been shaped in such a way

[1]) A. L. Cockroft and S. C. Curran, Rev. Sci. Instr. 22 (1951) 37.

[2]) B. B. Rossi and H. H. Staub, Ionization chambers and counters (McGraw Hill, New York, 1949) p. 93.

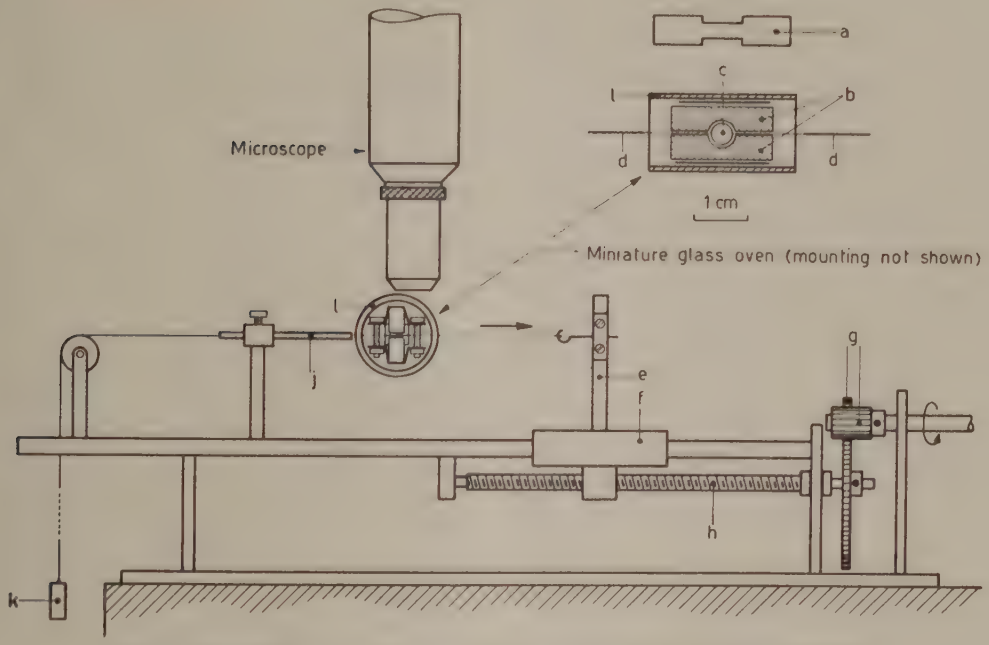

Fig. 1. Schematic view of arrangement for covering thin platinum wires with glass.
A section of the miniature glass oven is shown separately.

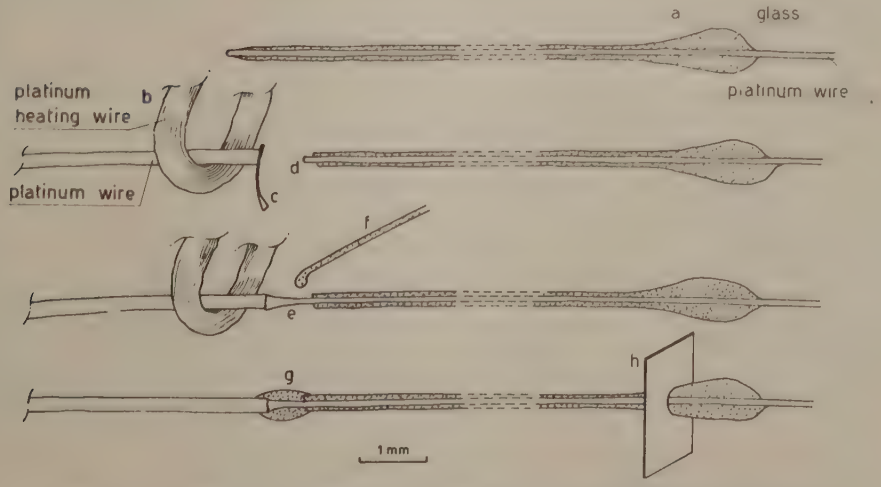

Fig. 2. The joining of a normal wire to a glassed wire of the same total thickness.
The junction is smoothed by a bead of lead glass.

that a small space (c) can be formed between the strips in the middle. Silver leads (d) are molten to both ends of the Pt-strips, by which they can be heated electrically. The glass is molten in the loop (c) which has a size of 3 to 4 mm. The thin platinum wire is drawn through the glass by a metal strip (e) fastened on a slide (f) which is moved by a synchronous motor (1 r.p.s.) through the toothed wheels (g) and the screw (h). The speed of the slide is about 1 cm per minute. The wire is guided by a hollow needle (j) and stretched by a small counterweight (k). The oven is surrounded by a quartz tube (l) for heat insulation, which is provided with small holes for the wire to be passed and a window through which the wire is observed, after coming out of the glass, by a microscope. The eyepiece of the microscope is provided with a graticule scale by which it is possible to measure and controle the thickness of the glass envelope during the process. The thickness is regulated by adjusting the oven temperature with the heating current. Wires were prepared with glassed lengths of about 5 cm, at the end of which the glass envelope was thickened to about 1 mm by lowering the oven temperature. The bead thus obtained (fig. 2, (a)) is convenient for mounting the wire in the counter. Actually prepared wires were usually somewhat thicker than the required value, but not more than 20%. Measurements have shown that this tolerance is sufficiently low for the purpose. Table 1 gives diameters of the wires prepared.

TABLE 1.

DIAMETERS OF GLASS-COVERED PLATINUM WIRES

Type of wire	1	2	3	4
Thickness of Pt-core, mm	0.05	0.07	0.05	0.10
Total thickness, mm	0.10	0.15	0.20	0.20

The method of joining the glassed wire end to end to the counter wire is illustrated by fig. 2 on a much enlarged scale. The operation is carried out on the table of a binocular microscope. On this table a platinum wire is mounted, having a thickness of 0.5 mm, which forms a loop (b) in the focal plane of the microscope. The wire can be heated electrically and serves to heat small parts of the thin wires. The end of the central part of the wire is led through the loop and, if this wire is made of platinum, a very small thin strip of silver (c) is molten to it, which serves as a solder. The end of the glassed wire is cut and a very short length of the platinum core is made free of glass (d). This is then brought into contact with the end of the central wire, and a joint is made by melting the silver (e). After this, the junction is covered with lead glass by heating below the melting point of silver (960° C) and supplying the glass in the form of a thin wire (f). In this way a smooth surface is obtained (g), thus avoiding spurious discharges. The glass also gives strength to the junction. The thickening is small enough to give only negligible distortion of the electric field in the counter.

The sensitive part of the wire is at the other end (not shown in fig. 2) limited by a small insulating glass bead, which is made with the same equipment.

After completion of the wire system the gold layer is evaporated on the glassed part, the other parts, including the glass beads being carefully screened. A small metal strip (h) provided with a small hole, and attached to the bead (a) with araldite, serves simultaneously for mounting the wire and for electrical contact with the gold layer. A little aquadag may be applied to ensure a reliable contact.

We have also used stainless steel wires, which are often preferable because of their hardness. These were attached to the platinum core of the glassed wire with "silver solder" (melting point 650° C) using a suitable flux. No glass can then be used to cover the junction but a suitable substitute is araldite, which is polymerized after application. The insulating bead was also made of araldite in this case.

3. Applications

If the screening electrode is kept at a fixed potential, the parasitic capacitance of the wire

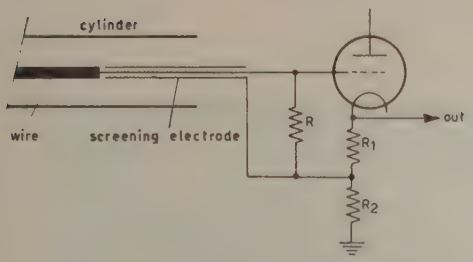

Fig. 3. Reduction of effective wire capacity using a cathode follower.

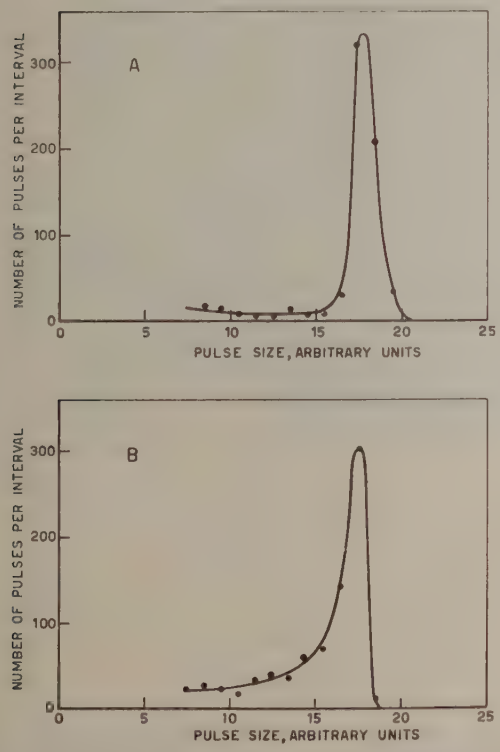

Fig. 4. Pulse size distributions from nitrogen filled proportional counters irradiated with thermal neutrons showing the influence of end effect.
A: End effect eliminated by the method described in this paper. B: Counter with end effect caused by guard tubes.

system is increased by the capacitance between these two electrodes. This capacitance amounts to about 30 cm for the wire types 1, 2 and 4 of table 1 and about 17 cm for type 3, if lengths of 5 cm are used. If this effect is undesirable, a cathode follower may be used, in the way as shown in fig. 3. A reduction of the effective capacity between the wire and the screening electrode by a factor of 10 is easily obtained with this method.

The performance of a counter provided with a wire prepared in the way described has been checked by filling with nitrogen and irradiating with thermal neutrons. By the (np) reaction, ionizations are produced in all parts of the gas volume, which should give rise to pulses of equal size. Fig. 4A shows the pulse size distribution taken from such a counter with a cylinder diameter of 5 cm and a wire thickness of 0.1 mm, filled with 1 atm of nitrogen. There is a good uniformity in pulse size, in contrast to fig. 4B, showing the result obtained with a similar counter, in which the ends of the wire are shielded with tubes of 5 mm diameter, at the same potential as the wire. The influence of the field distortion at the ends is clearly seen. Counters, provided with wires of the type described in this paper, have been used satisfactorily for neutron scattering experiments[3]).

4. Acknowledgements

The author wishes to thank Professor H. Brinkman, the Director of this laboratory for his stimulating interest in this work. The work was part of the research program of the "Stichting voor Fundamenteel Onderzoek der Materie" (F.O.M.) subvented by the Netherlands Organization for Pure Scientific Research (Z.W.O.).

[3]) C. P. Sikkema, Nuclear Physics 3 (1957) 375.

NUCLEAR INSTRUMENTS 1 (1957) 152–158; NORTH-HOLLAND PUBLISHING CO. – AMSTERDAM

A γ-RAY COLLIMATOR AND EXPANSION CHAMBER FOR USE WITH THE 340 MeV ELECTRON SYNCHROTRON

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Received 2 March 1957

This paper describes a collimator and Wilson type expansion chamber used at Glasgow University for the study of nuclear photodisintegration. The collimated beam has a diameter of 2.0 cm in the beam room, 6 metres from the machine target. The beam room is shielded against background radiation from the machine by a lead and concrete screen. The cloud chamber control system is very flexible and allows chamber and machine operations to be accurately synchronised.

1. Introduction

This paper describes a cloud-chamber and γ-ray collimator used with the electron synchrotron for the study of nuclear photodisintegration. The system has been constructed in such a way that the collimator is permanently installed as part of the synchrotron equipment, but the cloud chamber and its ancillary equipment is mounted on trolleys, so that when the chamber is not being used the collimator is available for other experiments.

2. Synchrotron

The synchrotron has already been briefly described by McFarlane *et al.*[1]), but it is important to restate here those features of the machine which are of most importance for cloud chamber work. The peak electron energy available at present is 340 MeV. The γ-ray beam is produced by the electron beam striking a tungsten target placed perpendicularly to the median plane of the machine. A bremsstrahlung spectrum is produced with the γ-rays emitted in a fairly narrow cone in the forward direction with respect to the electron beam. The γ-ray beam passes through the ceramic wall of the vacuum chamber, between two of the uprights of the magnet yoke, through an aperture in the wall of the synchrotron chamber and so into a separate beam room. Thus the experimental equipment is largely isolated from disturbance due to heat, noise and stray radiation from the machine itself.

The machine is synchronised to the 50 cycle A.C. mains, and was set up to produce a pulse of electrons (and hence of γ-rays) on each eleventh mains cycle. For cloud chamber work it is essential to arrange for "single-shot" working, with the synchrotron triggered only when the cloud chamber is ready to receive the beam. Even under single-shot conditions the machine is still locked to the mains and can only produce a pulse at times spaced eleven cycles apart. As will be seen below this feature of the machine has considerable influence on the details of the cloud chamber control system.

The synchrotron control room is situated at some distance from the machine itself, and is thoroughly shielded against radiation. It is in principle possible to control all operations, including cloud chamber operations, from this room. However, it is often very desirable to observe the cloud chamber directly in order to verify that it is operating correctly. Since the machine is only allowed to produce radiation in short bursts and at fairly long intervals (about one every two minutes) it is possible to make such observations from a suitable position without risk of radiation injury.

[1]) W. McFarlane, S. E. Barden and D. L. Oldroyd, Nature **176** (1955) 666.

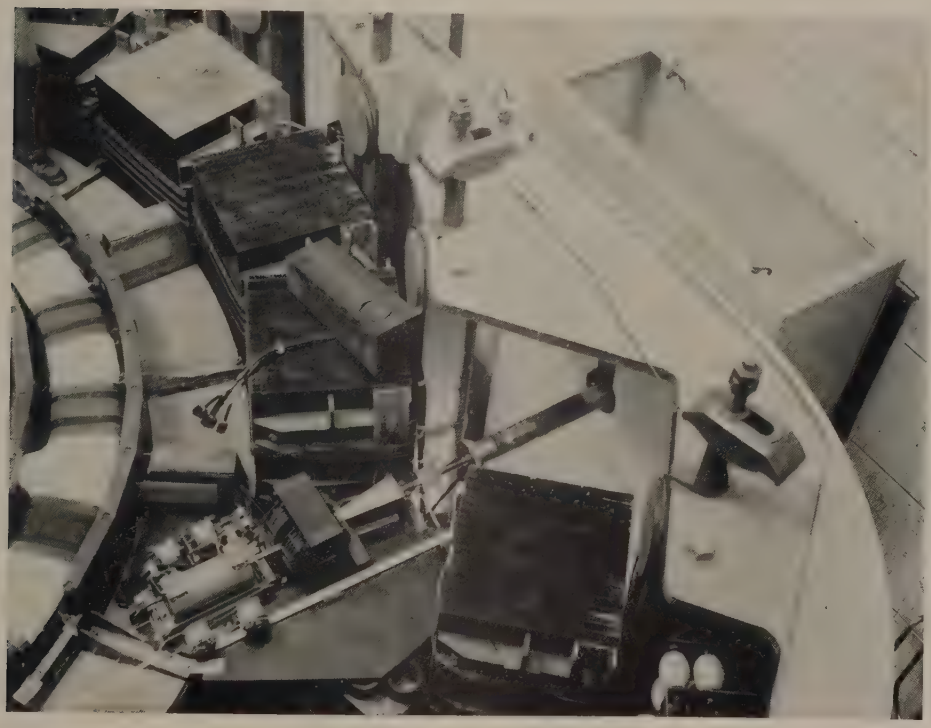

Plate 1. Collimator Installed on Synchrotron.

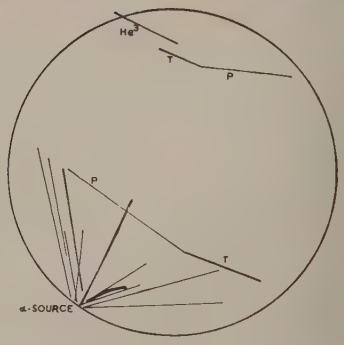

Plate 2. Description.

The photograph shows tracks in a helium filled expansion chamber. The photon beam enters from the bottom of the picture. The shower of secondaryelectrons is clearly visible. Three α-particle disintegrations are present, two being $He^4(\gamma, p)T^3$ and one $He^4(\gamma, n)He^3$. The α-particle source (lower left) is included to provide a check on chamber operation.

3. Collimator System

The point in the beam room which is nearest to the machine and at which experiments can be carried out is about six metres from the target. It is obviously desirable that the beam available at this point should be well defined in position, angular divergence and cross-section. The beam emerging from the machine has a bell-shaped intensity distribution across its diameter, with angular width at half maximum of 0.46 degrees. At six metres from the target this corresponds to a diameter of 4.8 cm and the wings of the distribution spread out much further. Thus the geometry of the beam is not sufficiently well defined for many experiments. The purpose of the collimator is to select the central, most intense, part of the beam. The diameter of the collimated beam at six metres is approximately 2.0 cm, and its angular divergence 0.20 degrees. Unwanted background is cut out by shields built round an evacuated beam tube which leads from the collimator proper into the beam room. This beam tube passes through a "scrubbing" magnetic field which deflects charged secondary particles out of the beam. There is thus available in the beam room a well-defined, clean γ-ray beam with a minimum of background radiation.

3.1. COLLIMATOR AND BEAM TUBE

A median plane view of the collimator and beam tube is shown in fig. 1 and a photograph of part of the system in plate 1. The collimator and beam tube are evacuated by means of a diffusion pump, but no vacuum connection exists between the collimator and the synchrotron. Thus the machine is protected against the ill-effects of a sudden inrush of air if a window collapses or other vacuum faults develop in the beam tube or any equipment connected thereto. The beam originally passed through about 2 cm of ceramic before entering the air, but recently a thin window has been built into the wall of the vacuum system, considerably reducing the amount of absorbing material through which the beam has to pass.

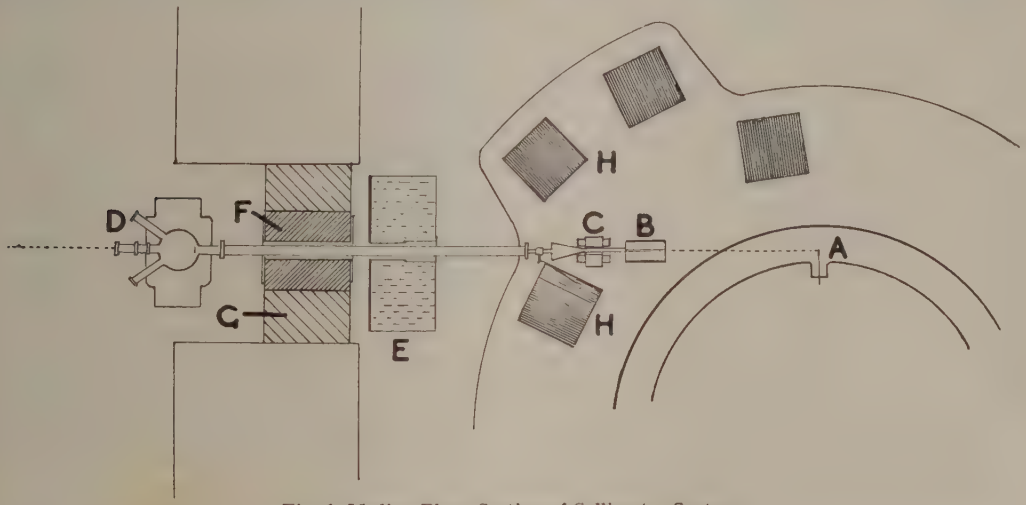

Fig. 1. Median Plane Section of Collimator System.

A Synchrotron Target B Collimator C Scrubbing Magnet D Pair Spectrometer
E Water Tank F Lead Shielding G Barytes loaded Concrete H Part of Magnet Yoke

The collimator consists of a lead cylinder 9″ long, 4½″ diameter, with an axial hole ¼″ diameter. The position of the cylinder is governed by four motor-driven screws, one for horizontal and one for vertical movement at each end of the cylinder. A range of adjustment of about ¼″ is provided in each case. The motors, which are clearly visible in the photograph, are operated from the control room. The position of the cylinder is indicated by lamp signals on the

motor control panel. It will be seen from the figure that the collimator is inside the yoke of the synchrotron magnet, and is thus in a region of varying magnetic field, with a peak intensity of some hundreds of gauss. There is some slight vibration of the lead cylinder on its mounting and there is also some eddy current heating. The effects of these have been found to be negligible in practise.

The front of the collimator is sealed by a thin glass window, and is about half a metre from the point at which the beam emerges from the wall of the synchrotron vacuum system. A flexible metal bellows is used at the joint between the collimator and the next section of the system, to accommodate movements of the lead block.

After leaving the collimator the γ-rays pass between the poles of a D.C. electromagnet which produces a field of 5500 gauss. This deflects out of the beam secondary electrons produced by the γ-rays in striking the window at the front of the collimator and the inside surface of the $\frac{1}{4}''$ channel. To accommodate these deflected particles the beam tube is flared out from $\frac{3}{4}''$ to 2″ square cross-section at one foot from the D.C. magnet. The photon beam passes through a central aperture in the end of this flared section into an iron pipe $\frac{3}{4}''$ inside diameter. This can be surrounded by lead blocks to shield against background produced either in the machine or by the secondaries striking the end of the flared section. The whole of the collimator system up to this point is rigidly attached to the main synchrotron frame. Since the machine is mounted on springs a flexible bellows coupling has to be provided between the $\frac{3}{4}''$ iron tube and the next section, which is of 3″ diameter and 5 feet length. This passes through the shielding wall into the beam room, where it is coupled through a bellows to a pair spectrometer. This spectrometer is of conventional design, and is used to monitor the beam energy spectrum and intensity. The spectrometer radiator can be swung aside to permit the beam to pass cleanly through the spectrometer. The vacuum pumps are attached to the beam tubeby means of a "T" piece just beyond the spectrometer. At this point additional lengths of tubing or other fittings can be attached to suit the needs of a particular experiment. The arrangements used for expansion chamber work are described below.

3.2. SHIELDING

The main shielding materials used are lead, concrete and water. The shielding arrangements consist of the lead blocks closely surrounding the beam as mentioned above, a water tank and cadmium sheet to slow down and capture neutrons, and a lead and concrete screen. The water tank is installed in the space between the synchrotron frame and the wall separating the synchrotron chamber from the beam room. It is 8 feet high, $3\frac{1}{2}$ feet wide and 17 inches thick, these dimensions being dictated by the space available. A metal cylinder $4\frac{1}{2}''$ diameter running through the tank provides passage for the beam tube. The side of the tank remote from the synchrotron is covered by a cadmium sheet 0.022 inches thick. The aperture in the beam room wall is closed as far as possible by a screen of barytes concrete blocks, two 9 inch blocks in thickness. Steel plates are clamped on each side of this wall by means of tie-bars, and the brass beam tube runs through a steel tube supported by these face plates. The gap left between the concrete blocks and the steel tube is filled with lead, blocks being used where possible and then lead shot poured in to fill the remaining space. The annular gap between the beam tube and the steel tube is also filled with lead shot. When it is desired to remove the beam tube it is only necessary to remove the shot from this comparatively small volume; the long section of the beam tube can then be withdrawn through the apertures in the water tank and the shielding wall. A lead cylinder 4 inches long, $1\frac{1}{2}$ inches internal diameter which fits into the beam tube on the synchrotron side of the pair spectrometer completes the shielding arrangements. This arrangement of shielding has been found to give a satisfactorily small background out of the γ-ray beam, and there seems to be no evidence of serious particle contamination of the beam itself.

3.3. ALIGNMENT

Alignment of the various components of the collimator and beam tube system to the required accuracy proved to be an operation of some complexity and difficulty.

First of all the cross-section of the beam was scanned with a small ionisation chamber to find its axis. A telescope was then set up to sight along the beam axis, looking towards the synchrotron, and a mark was made on the wall of the vacuum system at the point at which the beam emerged. This mark and the telescope cross-wire thus defined the beam axis. The collimator was then put in place and its position adjusted until, as viewed through the telescope, the central hole was symmetrically disposed with respect to the beam axis. Further adjustments were made by running the machine, and adjusting the collimator (by means of the motors) to obtain maximum intensity as recorded by a large ionisation chamber arranged so that the whole beam impinged on it. Finally, a small ionisation chamber was placed on the beam axis, as previously determined, and it was verified that the axial intensity had not

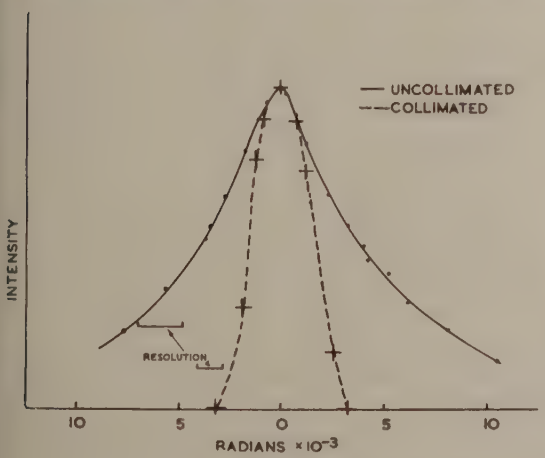

Fig. 2. Intensity Distribution in Photon Beam

been significantly affected by the insertion of the collimator. The beam tube was then assembled in sections, photographic films being exposed at each coupling to ensure that the tubing was being symmetrically placed round the beam.

Fig. 2 shows the distributions of ionisation across the diameter of the collimated and uncollimated beam, as measured with an ionisation chamber with the resolution shown.

4. Cloud Chamber

The cloud chamber used for the first experiments with the collimated beam is of similar design to that used by Wright *et al.*[2]). It is a conventional volume controlled instrument, with a sensitive volume 12 inches diameter and 3 inches deep. The wall consists of a glass cylinder of $\frac{1}{4}$ inch wall thickness, and the top is a $\frac{3}{4}$ inch "Triplex" plate. The normal pressure in the compressed condition is about $1\frac{1}{2}$ atmospheres. The fast expansion is controlled by an electromagnetic valve with separate "hold on" and "reset" solenoids. A separate valve is used to control slow expansion. The temperature is held approximately constant by circulating water from the mains supply through a collar round the heavy brass base, and the whole chamber is surrounded by a metal shield. The chamber is illuminated by two Mullard LSD 16 discharge tubes, and photographed stereoscopically by three independent cameras with lens axis vertical and film plane horizontal. The photographic background is provided by black velvet covering the bottom of the chamber.

The beam is brought into the chamber through a mica window 2 mg/cm^2 in thickness and 1.4 inches in diameter. This window is carried on the end of a brass tube 4 inches long and $1\frac{3}{4}$ inches outside diameter which can be inserted into a short brass tube cemented into the cloud chamber wall, so that the window is flush with the inside of the chamber wall. A gas-tight seal is obtained by means of "O" rings. The four inch tube is attached to the beam tube described above through a metal bellows. It is thus possible to adjust the cloud-chamber position so that the photon beam traverses a diameter. It will be noted that the only material between the front of the collimator and the sensitive part of the cloud chamber is the thin mica window.

[2]) I. F. Wright, D. R. O. Morrison, J. M. Reid and J. R. Atkinson, Proc. Phys. Soc. A **69** (1956) 77.

An approximate calculation indicates that in a chamber filled with helium the background of electron pairs produced in a window of the thickness used is large compared with that produced in the gas, but that in air the build-up of pairs produced in the gas is larger than the background from the window. It has been found necessary to use as thin a window as possible with a helium filled chamber in order to ensure that the background of electron tracks does not obscure the tracks of heavy particles arising from nuclear disintegrations.

5. Cloud Chamber Control System

A block diagram of the system is shown in fig. 3.

A Master Timer unit which is synchronised to the 50 cycle A.C. mains supplies a succession of pulses, normally spaced eleven mains cycles apart, and it is these pulses which trigger the operation of the synchrotron circuits. For single-shot working a gate in the path from master timer to magnet energising circuit is operated. This gate is normally closed, but the electron gun and radio-frequency systems are left running under the control of the master timer. When a γ-ray pulse is required the gate is opened and the magnet operates on the next master timer pulse. The precise timing of the gun and radio-frequency systems is then automatically governed by peaking strips in the magnetic field. This method of single-shot working is reasonably economical of power, but allows the gun and radio-frequency systems, which take several cycles of operation to reach steady operating conditions, to work under satisfactory circumstances.

The Dekatron Unit (see fig. 3) has already been described in outline by Reid[3]). It is essentially a Dekatron stop-clock running at mains frequency. Plugs and sockets are provided so that pulses can be picked off from the individual Dekatron cathodes. These pulses are fed to five independent output channels, and by adjusting the positions of the plugs the elapsed time between the clock being started and a pulse appearing in any given output channel can

[3]) J. M. Reid, Proceedings of Conference on Recent Developments in Cloud Chamber and Associated Techniques (University College, London, 1955) p. 218.

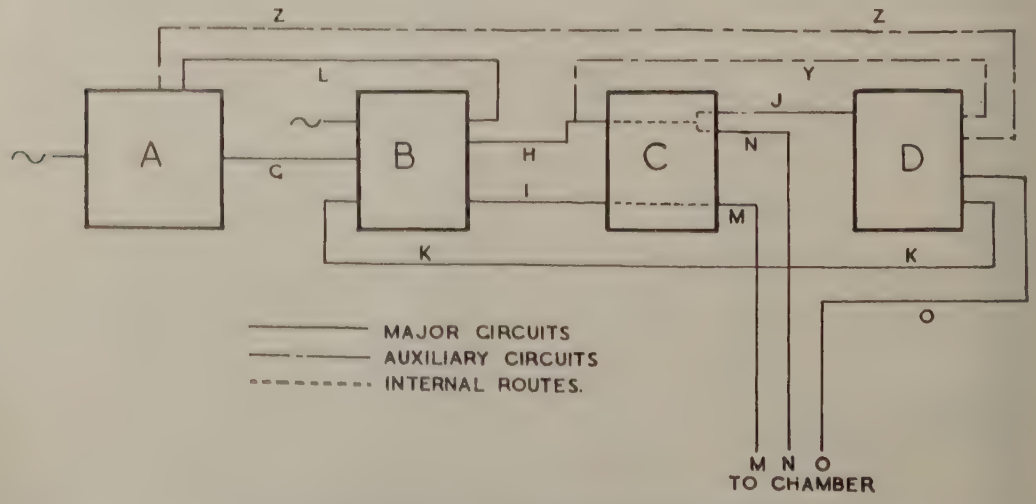

Fig. 3. Block Diagram of Cloud-Chamber Control Equipment.

A Synchrotron (and Master Timer) B Dekatron Unit C Cloud Chamber Control Unit D Slow Expansion Control Unit

Signal Paths.

G Master Timer Pulse
H Chamber Expansion Pulse
I Lamp Trigger Pulse
J Start Slow Expansion
K Chamber Ready Signal
L Synchrotron Trigger
M Lamp Flash
N Fast Expansion Valve
O Slow Expansion Valve
L Local Operation Loop
Z Synchrotron Gun Control

be varied in discrete intervals of 20 msec up to a maximum of 2 seconds. A signal is sent to the Dekatron Unit when the cloud chamber is ready to receive the beam, and the clock begins to run on receipt of the next pulse from the master timer. One output channel is used to control the gate in the magnet firing circuit referred to above. It is necessary to adjust the timing of this channel so that the gate is open at the moment when a master timer pulse is generated, i.e. in general a multiple of 11 main cycles from the time at which the stop-clock was started. Two further channels deliver pulses which control the chamber expansion valve and the discharge lamps. The timing of these relative to the beam pulse may thus be varied by the plug and socket arrangement. The final two channels are available for timing other gates or equipment should they be required.

The pulses for chamber expansion and lamp trigger are fed to the Cloud Chamber Control Unit. The "hold on" solenoid of the fast expansion valve is in the cathode circuit of a pair of parallel connected type 6L6 pentodes, the grids of which are driven into cut-off when the expansion pulse is received, and so the valve opens. A triggered multivibrator restores the pentodes to the conducting state 0.8 seconds after cut-off, and the re-set solenoid then operates to re-seat the valve ready for the next expansion. The expansion pulse also controls the opening of the camera shutters, which are solenoid operated, triggers the slow Expansion Control Unit (see below) and can be made to switch off the chamber clearing field. After the shutters close the film is automatically wound on. The lamp trigger pulse is used to close a relay which discharges a condenser through the parallel connected primaries of two induction coils which initiate the discharge of the flash tubes. The control unit has an array of supervisory signal lamps and switches so that all operations can be controlled manually if desired.

The Slow Expansion Unit contains a multivibrator, which drives a uniselector, one bank of which is used to select the value of the grid resistor which governs the period of the multivibrator. Thus as the uniselector steps round the resting period on a given step is governed by the value of the appropriate grid resistor. At one position of the uniselector the multivibrator is biassed off, and in this condition the "chamber ready" signal is sent to the Dekatron Unit, which operates as already described, triggering the cloud chamber and the synchrotron. As the chamber expands the multivibrator bias is removed by the signal from the Control Unit, and the uniselector begins to step round. The slow expansion valve is controlled by a relay operated by one bank of the uniselector. Provision is made for the selection of different numbers of slow expansions up to a maximum of five, and for varying the values of the grid resistors which govern (1) the period for which the slow valve is open and the interval for which it is closed between successive slow expansions; (2) the waiting period before and (3) the waiting period after the slow expansion sequence. After the second of these two waiting periods the uniselector returns to its original position, the "chamber ready" signal is again provided and the cycle is repeated. Thus the whole cycle is automatic, no operator being required except to monitor the synchrotron beam. The Slow Expansion Unit can perform certain auxiliary functions. If it is desired to operate the cloud chamber without the synchrotron, a "chamber ready pulse" can be fed directly to the Control Unit instead of to the Dekatron Unit. The electron gun of the synchrotron may be switched off for most of the chamber cycling time, provided that it is operated for several seconds before the machine as a whole is triggered. Suitable switching facilities are provided by the uniselector. As with the Control Unit, provision is made for lamp signals and manual operation.

6. Performance

The first experiment carried out with the cloud chamber and collimated γ-ray beam was a study of the photodisintegration of helium. An account of this work is in preparation (Atkin-

son *et al.*[4]). A typical photograph is shown in plate 2, to illustrate the performance of the equipment.

[4]) J. R. Atkinson, J. M. Reid and P. Swinbank, to be published.

We are grateful to Professor P. I. Dee, F. R. S. for his interest in this work. We also have to acknowledge the assistance of the workshop and technical staff in constructing the system and operating the machine.

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CONTINUOUS SCANNING IN TWO DIRECTIONS OF THE ION BEAM IN AN ELECTROMAGNETIC ISOTOPE SEPARATOR

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A system is described for continuos supervision of the shape and position of the image in the focussing plane of an electromagnetic isotope separator. Two thin needles—one horizontal and one vertical—are moved through the fixed beam. In this way a picture of the extension of the beam in both directions is obtained on an oscilloscope screen. Since even small changes in the shape of the beam can be observed, it is possible to maintain the focussing condition at maximum resolving power, and thereby to increase the effective separation power. The amplitude of the needle oscillation can be adjusted so that the whole mass spectrum of any element, except hydrogen, is covered.

1. Introduction

A mechanical beam scanning device has been developed in connection with the electromagnetic isotope separator at this Institute in order to obtain a continuous control of the focussing during the entire separation.

The beam is scanned by moving periodically a thin needle—the scanning needle—through the fixed beam. The position of this oscillating needle is transformed into an electrical signal and fed to the horizontal deflecting plates of an oscilloscope, while the vertical deflection is determined by the current to the needle. Thereby an oscilloscope tracing of the mass spectrum is obtained with which the focussing can be controlled.

The isotope separator[1,2]) is provided with a plasma ion source and here the shape and size of the plasma boundary at the outlet have an influence on the focussing condition[3]). Even if all the power supplies are well regulated, it is difficult to keep the shape of the plasma boundary constant during the separation, because the discharge in the ion source also depends on the vapour pressure which is difficult to control[4]). It is therefore very important to measure continuously the shape of the beam at the collector in order to be able to adjust to optimum condition during the separation.

The isotope separator is used mainly to prepare radioactive sources for beta- and gamma spectroscopy. Here, the direct deposition method is in general used. The ion beam in the isotope separator hits a thin foil mounted on the collector plate. This foil is transferred and used directly as the source in the beta spectrometer. It is therefore particularly important that the beam in the isotope separator is continuously controllable in both directions so that the activity may be deposited in a well defined area, small enough to be acceptable for the beta spectrometer. Therefore the isotope separator is provided with two movable needles, one vertically scanning needle (the y-scanner) and one horizontally scanning needle (the x-scanner).

It is normally possible to choose an ion beam that is not going to be collected and to use this as a reference beam. This reference beam is used partly to achieve position stabilization[5,6]), partly for controlling the focussing condition.

By letting the reference beam hit a fluorescent screen[7]) it is possible during the separation to

[1]) J. Koch, Proc. 1955 Harwell Isotope Conf. (1955) Chapter 25.

[2]) K. O. Nielsen, to be published.

[3]) O. Almén and K. O. Nielsen, to be published.

[4]) I. Schutten, G. I. Zilverschoon and I. Kistemaker Appl. Sci. Res. (1954).

[5]) G. J. Zilverschoon, Thesis (Amsterdam, 1954).

[6]) S. Thulin, Ark. Fys. **9** (1955) 107.

[7]) J. Koch and B. Bendt-Nielsen, Mat. Fys. Medd. Dan. Vid. Selsk. **21** (1944) no. 8.

have a visible control of the focussing condition. However, this method has the disadvantage that the fluorescent screen will give a misleading picture of the mass line after irradiation for a short time. Furthermore, at heavy masses, the dispersion is so small that it is difficult to let the reference beam hit the fluorescent screen and at the same time collect the neighbouring mass line.

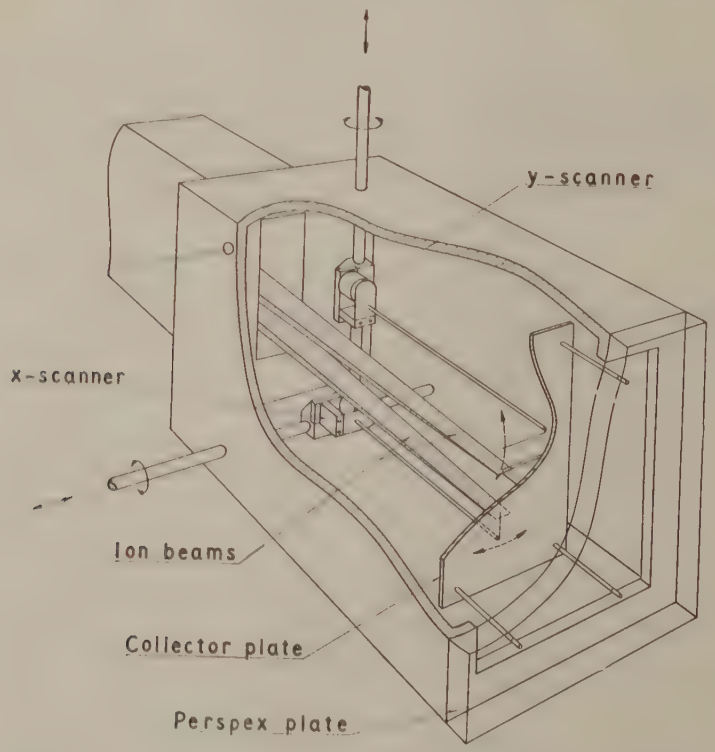

Fig. 1. Schematic drawing of the collecting chamber with the two scanners.

2. Technical Description

2.1. MECHANICAL CONSTRUCTION

The two needles are placed in the collecting chamber as shown in fig. 1. In addition to the picture of the mass spectrum, the y-scanner gives the width of the mass lines (resolving power). The x-scanner gives the distribution of the beam in the direction of the x-axis.

The two scanners which are similar in construction are shown in fig. 2. A stainless steel tube (1), 200 mm long, is soldered to a plate of soft iron (2). This plate is then riveted to a short spring (3), the other end of which is screwed to a frame (4). The tube, the iron plate, and the spring constitute an oscillating system, and the rigidity of the spring is adjusted so that the mechanical resonance frequency is 20–25 cycles per sec. Behind the iron plate (2) on the frame is mounted an electromagnet (5) which drives the oscillating system. A thin leaf spring (6) is also mounted on the iron plate (2). This spring presses on the corner of a piezoelectric crystal made of Rochelle salt† (7). The dimensions of the crystal are $18 \times 15 \times 1$ mm and it is mounted on the frame by compressing it between two rubber plates (8).

† After 24 hours in vacuum, the Rochelle crystal operates with diminished efficiency, probably because of evaporation of the water of hydration. By coating it with microcrystalline paraffin wax (B.S.O. 170) these difficulties are overcome.

The scanning needle (9) is an 0.2 mm thick tungsten wire and is mounted in a perspex plug (10) on the end of the tube (1). The electrical connection to the needle goes through the tube (1). The needle has a d.c. bias of the order of minus 85 volts (see section 2.4). Therefore, a variation in capacity caused by the vibration of the wire inside the tube will, in turn, create a noise signal (proportional to the d.c. bias). To make this effect negligible, the wire is made of a stiff bronze wire mounted in plexiglass plugs placed 40 mm from each other.

The y-scanner is mounted on a horizontal rod (fig. 1). By moving the rod, the position of the y-scanner can be adjusted in the direction of the y-axis. The maximum displacement is 100 mm. Furthermore, the rod can be turned, and in this way the needle of the y-scanner is adjusted in the direction of the x-axis. The amplitude of the needle of the y-scanner can be varied from 20 to 90 mm (see later).

The great amplitude is useful for mass identification while, during separation, we normally use so small an amplitude that only the reference beam is scanned.

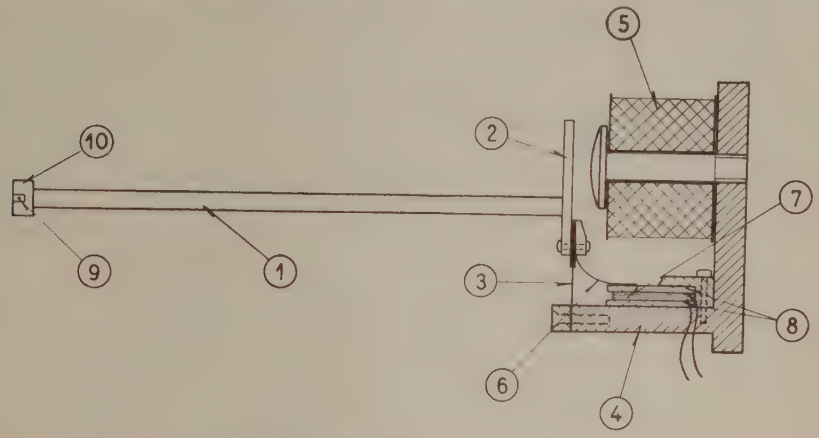

Fig. 2a. Schematic drawing of the scanner.

Fig. 2b. Photograph of the scanner.

The x-scanner is mounted on a vertical rod. By turning this rod, we can adjust the x-scanner so that the needle just passes through the reference beam. The vertical rod, and with this the x-scanner, is also movable in the direction of the x-axis.

placed in two positions. The lowest position is used in the case where the reference beam lies below the mass lines to be collected. The upper position—indicated by the dot- and dash line in fig. 1—is used when the reference beam lies above.

Both the y-scanner and the x-scanner are

normally adjusted so that the two needles pass through the reference beam only. In this way, unnecessary scattering of the beam by the needles is avoided.

back system will oscillate on the mechanical resonance frequency.

By driving the system on its own mechanical resonance frequency, it is possible to obtain a

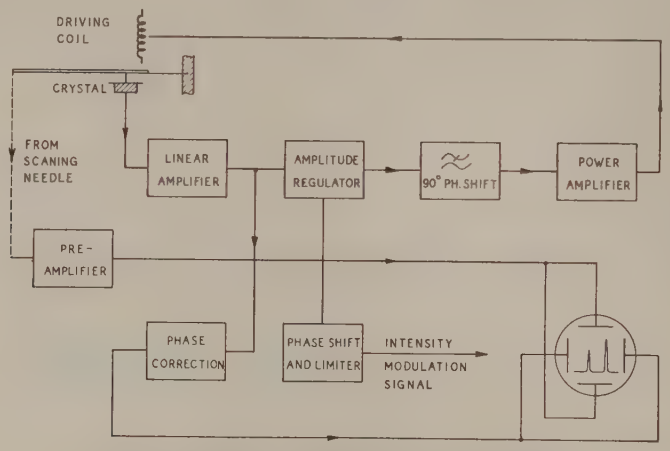

Fig. 3. Block diagram of the complete scanning system.

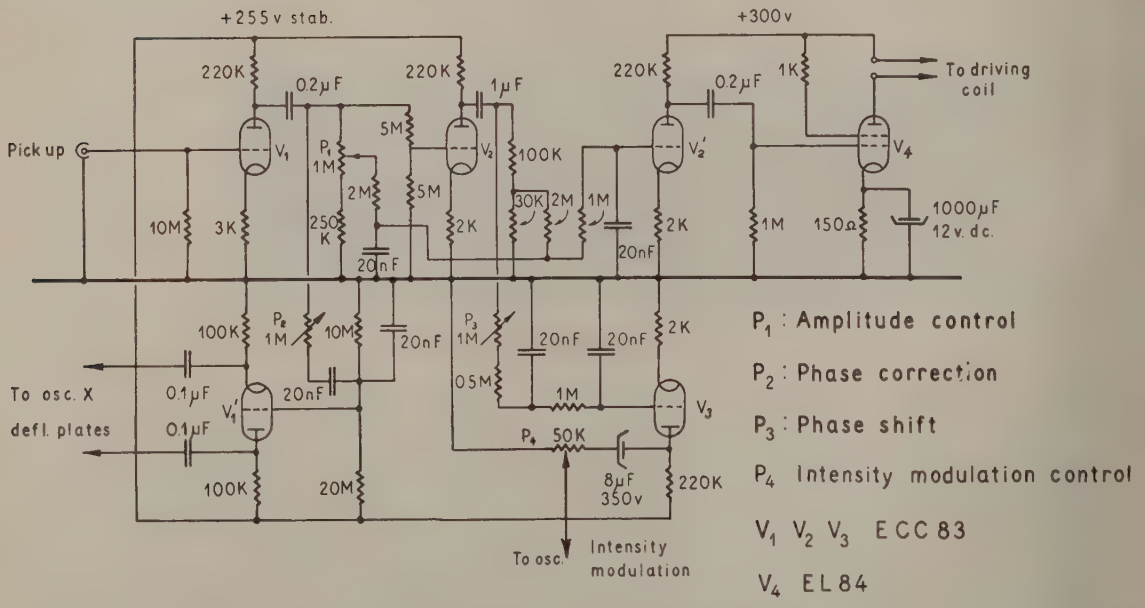

Fig. 4. Complete diagram of the electronic equipment.

2.2. OPERATION PRINCIPLE

The electrical signal from the crystal goes to an amplifier. The power stage from this amplifier drives the electromagnet (fig. 3), and this feed-

great amplitude for a small power input to the electromagnet.

The signal voltage induced in the crystal is proportional to the pressure of the leaf-spring on

this and is, therefore, a measure of the position of the scanning needle. After one stage of amplification, this signal goes to a phase-correcting circuit and then to the horizontal-deflecting amplifier of the oscilloscope.

As shown in fig. 3, the current to the scanning needle is measured by a preamplifier which is connected to the horizontal deflecting plates on the oscilloscope.

2.3. ELECTRICAL CIRCUIT DESCRIPTION

The diagram of the amplifier, which is a part of the feedback system, is shown in fig. 4. To

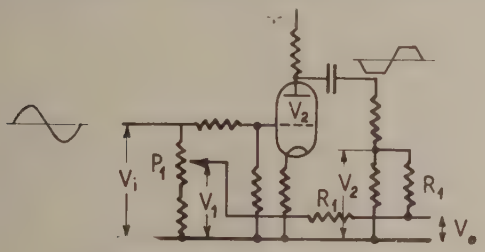

Fig. 5a. Amplitude regulator stage.

obtain good stabilization and regulation of the scanner amplitude, an amplitude-regulator stage (fig. 3) is introduced into the loop. The total loop gain is $A = A_0 \cdot V_0/V_i$, where A_0 is the amplitude-independent part of the loop gain and V_0/V_i is the gain of the amplitude regulator stage shown in fig. 5a. At very small amplitudes, this stage is a linear amplifier, while, at the amplitudes normally used, the tube operates as a limiter, and the gain V_2/V_i is, therefore, inversely proportional to the amplitude, as shown in fig. 5b. To the output signal V_2 is added the signal $V_1 = K \cdot V_i$, where K is given from the position of the potentiometer P_1. The total loop gain is then

$$A = A_0 \cdot \frac{V_0}{V_i} = A_0 \cdot \frac{V_2 + V_1}{2V_i} = \frac{1}{2} \cdot A_0 \cdot \left(\frac{V_2}{V_i} + K\right).$$

The variation of the loop gain as a function of the amplitude is given in fig. 5b. The resulting amplitude $(V_i)_1$ is the amplitude corresponding to a loop gain of unity; it can be varied by the potentiometer P_1. In this way, it is possible to obtain a well-defined amplitude over a range of amplitude corresponding to a factor of 4 or 5.

Between the limiter and the output stage is inserted a low-pass filter. It gives the necessary phase shift of 90° between the signal from the crystal and the current in the driving coil and, at the same time, it suppresses higher harmonics produced by the limiter.

The signal to the horizontal-deflecting plates of the oscilloscope is taken after the first linear amplifier stage. The phase can be corrected by the potentiometer P_2. The phase splitter allows a choice of polarity of the x-deflection. The signal for blanking the return trace is taken from the limiter (fig. 4). The first harmonic of this signal is phase-shifted 90° and then supplied to another limiting amplifier. In this way, we obtain a blanking signal of a nearly rectangular form with a size almost independent of the scanner amplitude. The phase and size are controlled by means of P_3 and P_4, respectively.

2.4. PREAMPLIFIER

The scanning needle is connected by a double screened cable to a resistor R. The voltage across R is measured by a cathode-coupled amplifier (fig. 6). The time constant of this circuit must be less than 5×10^{-5} sec to prevent distortion of

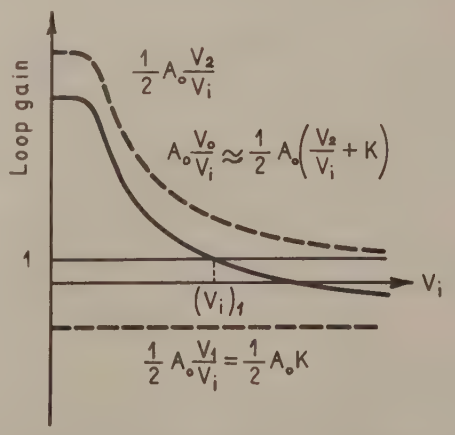

Fig. 5b. Loop gain as a function of the amplitude.

the picture of the mass spectrum at a scanner frequency of 25 cycles per sec, an amplitude of 90 mm, and a resolving power of about 1000. By connecting the inner screen of the cable to

the cathode of the amplifier tube, the influence of the cable capacity, and hence the time constant, is reduced. At highest sensitivity, a beam current of the order of 10^{-8} to 10^{-9} amp can be observed. The compromise between sensitivity and time constant is chosen so that there is some distortion at the highest sensitivity.

The scanning needle and the amplifier input have a d.c. bias of approximately minus 85 volts, x-scanner needle is 50 mm. This means that the full width at half maximum is about 5 mm.

The large amplitude of the y-scanner is also important when running the ion source with charging materials that give "sidebands". For instance, it is valuable, when separating Re (Re_2O_7 is used as charging materials), to be able simultaneously to cover both the mass spectrum from Re^+ and the sideband from ReO^+.

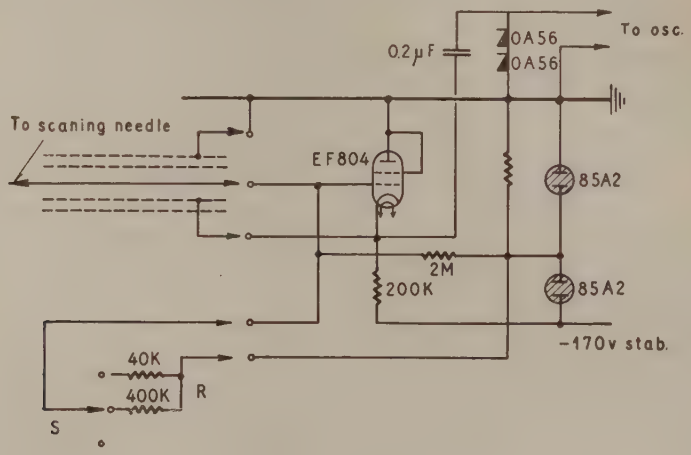

Fig. 6. Preamplifier.

which, due to secondary electrons, increases the sensitivity, and hence the signal-to-noise ratio, 3 to 5 times. In order to avoid distortion in the picture of mass spectrum, the d.c. bias must also be so high that the influence of secondary electrons is independent of the geometry.

The two diodes OA 56 give a d.c. restoring of the signal before it is fed to the d.c. coupled amplifier of the oscilloscope.

3. Discussion

The maximum amplitude of the y-scanner is so great (about 90 mm) that it is possible to cover the mass spectrum of all elements heavier than lithium. Fig. 7a shows the mass spectrum of krypton. The distance at the collector between the mass lines 78 and 86 is 76 mm. Fig. 7b gives the distribution of the beam in the direction of the x-axis. The amplitude of the

The lens system placed between the ion source and the analyzing magnet is constructed so that a two-directional focussing of the beam is achieved (O. Almén and K. O. Nielsen[3])). If, however, the reduction of the beam width in the direction of the x-axis is carried too far, the resolving power in the other direction is decreased. By using both the x- and y-scanner, and at the same time measuring the beam current to the target, it is possible to adjust for optimum conditions.

While the scanner described in this paper has only recently been put into operation, a preliminary y-scanner has been used with good results for more than nine months.

The continuous scanning of the fixed beam is also very important in avoiding contamination of the target. When separating heavy isotopes, where the mass dispersion is small (about 4 mm at Pb), it may be difficult to discover when the

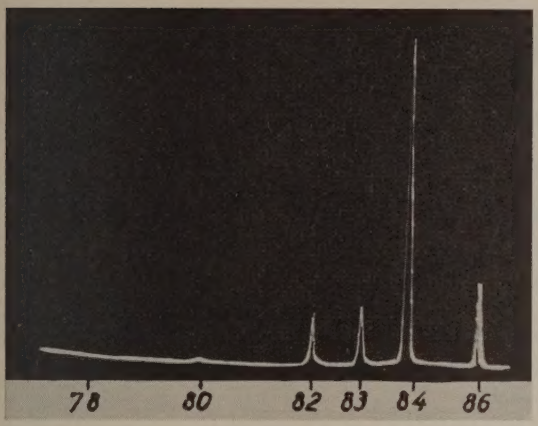

Fig. 7a. Mass spectrum of krypton. The amplitude of the y-scanner is 90 mm.

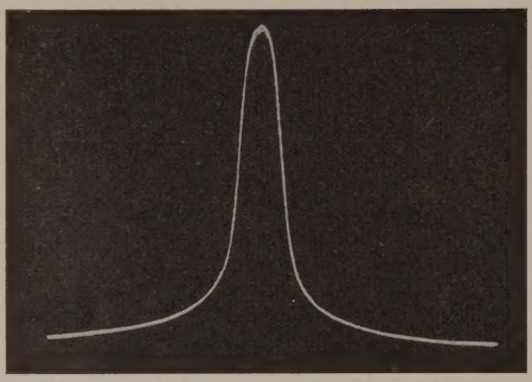

Fig. 7b. Distribution of the krypton beam in the direction of the x-axis. The amplitude of the x-scanner is 50 mm.

pin for position stabilization intercepts the neighbouring mass line. Using the continuous beam scanner, such a defect is observed immediately, as the mass spectrum on the screen will jump one mass unit.

We wish to express our gratitude to Professor Niels Bohr for his continued interest in our work and for the excellent working conditions offered at his institute.

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CONFERENCES

INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE

at the Weizmann Institute of Science, Rehovoth, Israel, September 9–16, 1957

President: G. RACAH

Advisory Committee: B. M. BLOCH, S. G. COHEN, N. ROSEN, S. SAMBURSKY, A. DE-SHALIT, K. SITTE, I. TALMI

Opening Address — G. RACAH: The seniority quantum number and its applications in nuclear spectroscopy.

Shell model evidence in nuclei — B. H. FLOWERS, *Chairman:*

R. J. EDEN: Foundations of the shell model.
I. TALMI: Energies or light nuclei.
D. KURATH: Intermediate coupling.

The unified model in theory and experiment — A. BOHR, *Chairman:*

R. E. PEIERLS: Foundations of the unified model.
B. MOTTELSON: Survey of solved and open problems.
L. WILETS: Fission and the unified model.

Beta decay in theory and experiment — O. KOFOED-HANSEN, *Chairman:*

E. J. KONOPINSKY: The theoretical significance of precise beta decay measurements.
L. M. LANGER: The measurement of shapes of beta spectra.
R. SHERR: Zero-zero transitions in beta spectra.

Parity violation in beta decay—S. B. TREIMAN†, *Chairman:*

T. D. LEE: Theoretical implications of parity violations in beta interactions.
C. S. WU: Experimental implications of parity violations in beta interactions.

Electromagnetic transitions in nuclei — M. GOLDHABER, *Chairman:*

D. WILKINSON: Transition rates and selection rules in light nuclei.
I. BERGSTRÖM: Regularities and systematics in heavy nuclei.
A. DE-SHALIT: Effects of configuration interaction on electro-magnetic transitions.

Extranuclear effects on angular correlation — M. DEUTSCH, *Chairman:*

A. ABRAGAM: General theory of extranuclear effects.
H. FRAUENFELDER: Measurements of magnetic and quadrupole moments of excited states.
R. M. STEFFEN: Beta-Gamma angular correlation.

Effects of the finite size of the nucleus — M. ROSE, *Chairman:*

L. A. SLIV: Phenomena affected by the finite size of the nucleus.
A. H. WAPSTRA: Accurate measurements of conversion coefficients.
P. F. ZWEIFFEL: Ratios of K-capture to positron-emission.

The measurement of very short nuclear life-times — A. C. MITCHELL, *Chairman:*

S. DEVONS: Techniques involved in measuring life-times shorter than 10^{-10} sec.
F. R. METZGER: Resonance fluorescence.
S. G. COHEN: Lifetimes of excited states produced by a decay.

Instruments of nuclear spectroscopy — K. SIEGBAHN, *Chairman:*

T. R. GERHOLM: Applications of magnetic spectroscopy and coincidence techniques.
J. W. DUMOND: Gamma Ray measurements by means of crystal diffraction.

A 45-minute discussion led by the chairman will conclude each session. Those wishing to take part in the discussion will be asked to submit, by the end of July 1957, a brief resumé of their comments in order to facilitate the conduct of the discussion.

† Not yet confirmed.

SOCIETA ITALIANA DI FISICA

The Italian Physical Society is organizing the Third International Conference on Ionization Phenomena in Gases thereby continuing the series of Conferences initiated by A. von Engel at Oxford in 1953 and followed up by A. B. Dorgelo at Delft in 1955. The Third Conference will be held in the building of the "Fondazione G. Cini" in Venice from 11th to the 15th June 1957.

The subjects to be discussed are devided into the following four general Sections:

(1) Fundamental processes in ionized gases.

(2) Mechanism and properties of various types of discharges.

(3) Nuclear reactions in discharges; contraction mechanisms, neutron production, etc.

(4) Technical and instrumental questions; applications.

In every Section will be presented General Surveys and short communications on the various topics.

English will be the preferred language.

The proceedings of the Conference will be published in the Supplemento of Il Nuovo Cimento.

All those who wish to attend the Conference or require further information are asked to write before March 15, 1957 to the General Secretary of the Conference: Prof. Ugo Facchini (Laboratori CISE, Via Procaccini 1, Milano, Italy), who will send them the application form.

INTERNATIONAL CONFERENCE ON RADIO-ISOTOPES IN SCIENTIFIC RESEARCH

An International Conference on Radio-isotopes in Scientific Research will be held in Paris from 9 to 20 September 1957. This Conference is being convened by Unesco, after consultation with the United Nations Secretariat and interested Specialized Agencies, in particular the World Health Organization, the United Nations Food and Agriculture Organization and the World Meteorological Organization.

The Conference will be strictly scientific in character. Its purpose is to bring together a large number of specialists in the various scientific disciplines interested in the use of radio-isotopes, so that they may submit the results of their research and exchange information and views on a series of subjects in which developments are proceeding at a particularly rapid pace. The Conference will therefore be devoted to the presentation and discussion of scientific papers dealing with original research, and will not be empowered to adopt resolutions or make recommendations.

Section 1
Radio-isotopes in the physical sciences

Section 2
Radio-isotopes in the biological sciences

All supplementary information can be obtained either from Unesco — Radio-isotopes Conference — 19 avenue Kléber, Paris 16e, France, or from the competent national authorities in each country.

CONFERENCE ON NUCLEAR STRUCTURE

Pittsburgh, June 6–8, 1957

(I) *Thursday morning:* Properties of Nuclear Matter — H. BARSCHALL, *Chairman:*

R. E. PEIERLS: The optical model.
N. M. HINTZ: Optical model experiments with charged particles.
L. WILETS: Consequences of nuclear shape.

(II) *Thursday afternoon:* Theory of nuclear matter — K. BRUECKNER, *Chairman:*

H. A. BETHE: General theory.
V. F. WEISSKOPF: Note on some qualitative considerations.
W. J. SWIATECKI: The nuclear surface.

(III) *Friday morning:* light nuclei — D. R. Inglis, *Chairman:*

J. B. FRENCH: The approach from the shell model.
H. E. GOVE: Experiments suggesting collective behaviour of light nuclei.
R. A. FERRELL: Theory concerning collective behaviour of light nuclei.
S. E. DARDEN: Polarization of neutrons at low energy.

Round table concerning the ground state wave function of the 14 body nuclei
(Members of panel to be announced)

(IV) *Friday afternoon:* Reactions — G. BREIT, *Chairman:*

H. FESHBACH: The statistical model.
R. SHERR: Summary of experiments indicating direct collisions.
R. F. CHRISTY: Survey of reaction mechanisms.

(V) *Saturday morning:* Heavier nuclei — D. H. WILKINSON, *Chairman:*

G. S. GOLDHABER: Recent advances on the systematics of even-even nuclei.
W. NIERENBERG: Moments of radioactive nuclei.
R. K. SHELINE: Intermediate coupling and collective behaviour of nuclear levels.
F. COESTER: The moment of inertia problem.

BOOK REVIEW

Progress in Low Temperature Physics, Volume II (1957). Editor, C. J. Gorter (North-Holland Publishing Company, Amsterdam, 480 pages, price Guilders 42– (84 s.))

The first volume of this book (published 1955) was largely devoted to the main fields of low temperature physics: liquid helium, superconductivity and magnetism. In this completing second volume new aspects of the quoted three fields have been considered. Thus the properties of liquid helium are treated in four articles by J. de Boer, H. C. Kramers, P. Winkel *et al.* and K. R. Atkins, and in an article by B. T. Matthias, superconductivity in the periodic system is considered. But also other topics such as specific heat and thermal expansion of solids (D. Bijl) and properties of solid helium (C. Domb and J. S. Dugdale) are reviewed. For the readers of this journal the very instructive article by M. J. Steenland and H. A. Tolhoek on orientation of atomic nuclei at low temperatures might be of the greatest interest. F. H. Spedding *et al.* give a very interesting survey of electrical, magnetic and thermal properties of the rare earth-metals at low and normal temperatures according to recent measurements. Other contributions are: E. H. Sondheimer, Electron-transport phenomena in Metals; V. A. Johnson and K. Lark-Horovitz, Semiconductors at low temperatures; D. Schoenberg, The de Haas-van Alphen effect (Oscillatory variation of magnetic susceptibility with the field in certain crystals); C. J. Gorter, Paramagnetic relaxation; H. van Dijk and M. Durieux, The temperature scale in the liquid helium region. (The historical development of the temperature-scale problem in question is excellently reviewed in this article.)

The volume contains about 1000 references. Certain fields of low temperature physics have, as the editor remarks, designedly been omitted in the book (for instance cryogenic technique and magnetic resonances). These are as a rule topics adequately covered elsewhere in recent publications. As to the fields treated, the book deserves to become a much used source for workers in low-temperature and atomic physics.

J. O. LINDE